COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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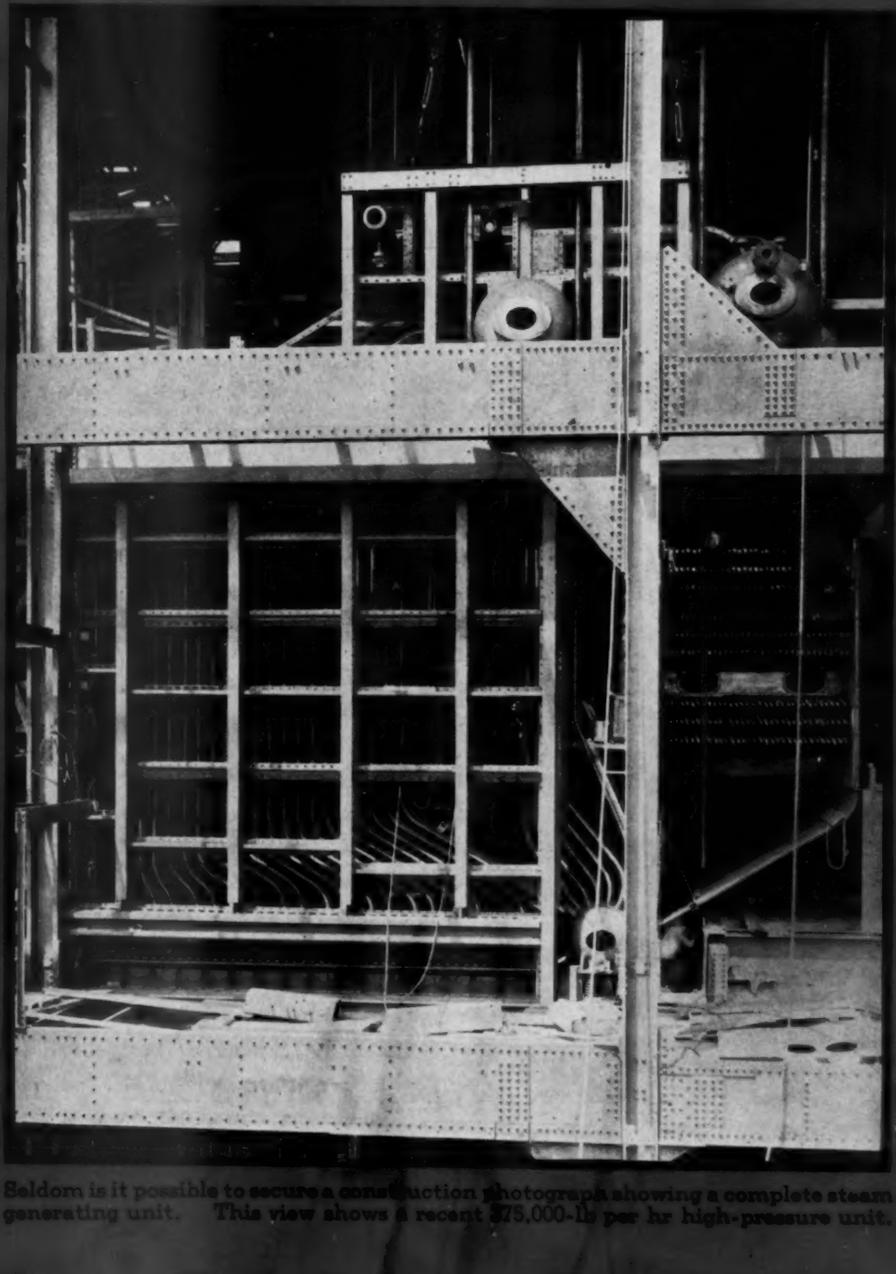

Seldom is it possible to secure a construction photograph showing a complete steam generating unit. This view shows a recent 375,000-lb per hr high-pressure unit.

Laguna Verde Generating Station in Chile

Judging Coal Values

Developments in Central Station Power Plants

Single Boiler Meets Refinery Steam Requirements

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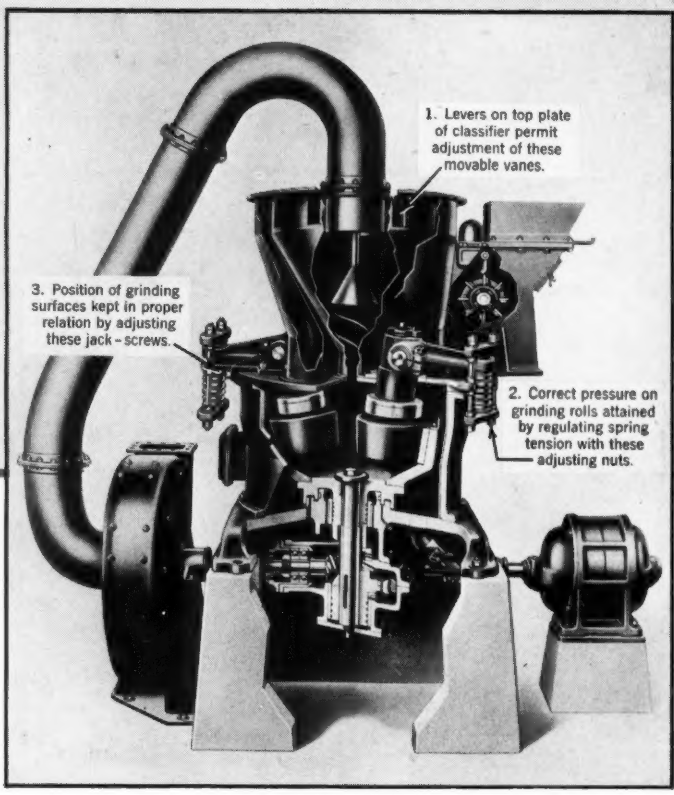

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME TEN | NUMBER TEN

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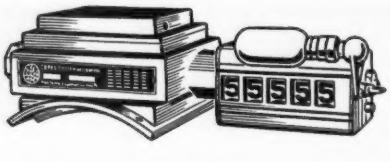
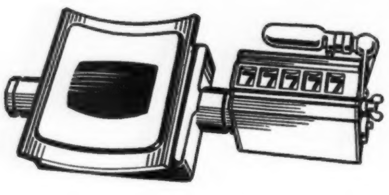


Helps build boiler efficiency. Gives an accurate, continuous reading of how much coal is fed to each stoker—indicating inefficient firing more quickly than any check of stoker revolutions or weigh larry reports. Inexpensive to buy, install and operate. Pays for itself quickly by making it easy to eliminate instantly operating inefficiencies. Saves time. The large illuminated dial is easily read at a distance of 30 feet.



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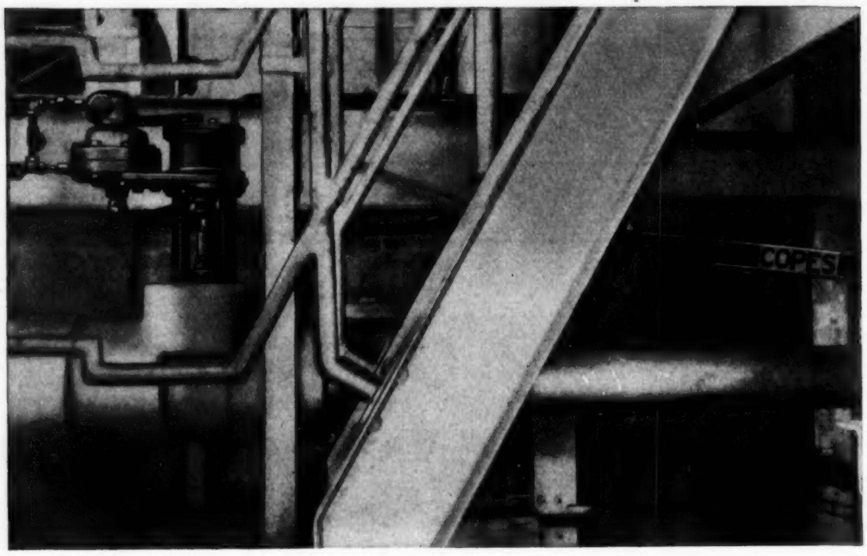

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EDITORIAL

SO_2 Pollution in Chicago

The results of a recent survey of atmospheric pollution by sulphur dioxide in Chicago, as made jointly by that city's Smoke Inspection Department and the Engineering Experiment Station of the University of Illinois, have just been released by the latter. These reveal some interesting facts, some of which are at variance with what might be expected. For instance, in certain typical manufacturing districts the average concentrations were less than those found in some of the congested residential sections; and, except under abnormal weather conditions, they were very much less than those measured in the Loop, or business district, which, with the exception of railroad yards, showed the highest average concentrations of all, namely, 0.43 ppm. Depending upon the wind direction, from 50 to 70 per cent of the sulphur dioxide pollution resulted from sources within the Loop itself.

Certain of the residential sections, particularly on the north side, in which much of the domestic heating is done with gas, oil and high-grade coal, showed as low as 0.05 to 0.09 ppm, whereas others ranged from 0.2 to 0.3 ppm. In these localities the conditions were seasonal.

Measurements taken in the vicinity of one of the large steam generating stations gave an average SO_2 concentration of 0.29 ppm on the leeward side and 0.03 ppm on the windward side; whereas those taken near railroad roundhouses averaged 0.67 ppm and reached as high as 1.61 ppm for short periods preceding hours of heavy traffic.

The steel mills, usually the smokiest and dustiest of all the industries, showed an average SO_2 concentration of only 0.05 ppm and air in the vicinity of the stock yards revealed only slight traces of SO_2, due probably to neutralization by the products of decomposition of the organic matter.

It would appear from the investigation that low chimneys, discharging gases resulting from the combustion of high sulphur fuels, contributed the major part of the pollution, as measured by portable equipment mounted on a motor truck. This may account for the relatively better showing in the vicinity of the manufacturing plants and generating stations that employ high stacks. Of course, weather conditions exerted a marked influence and on foggy or gusty days were responsible for concentrations near the ground several times those measured under normal conditions. Thus there was a tendency to nullify the effect of higher stacks at such times. As to the Loop district, it is possible that the existence of many tall buildings may have influenced the diffusion of gases discharged from the chimneys of adjacent lower buildings and thus partly accounted for the high concentrations in this section.

While opinion is divided as to the concentrations of sulphur dioxide in the atmosphere that are detrimental to public health, other earlier investigations have established its effect on buildings and metal parts. For some years past this has been a serious problem in England where frequent heavy fogs have intensified the situation and made necessary steps to alleviate it. Under pressure of local ordinances it has become necessary for some large plants to wash the stack gases but the expense incurred is considerable and difficulties of waste disposal have been encountered. Such methods would appear prohibitive for such cities as Chicago. The suggestion is made, however, that general use of washed coal, cleaned by methods already available, would go far in reducing the atmospheric pollution from SO_2 in this and other communities that are largely dependent on the use of high sulphur coals.

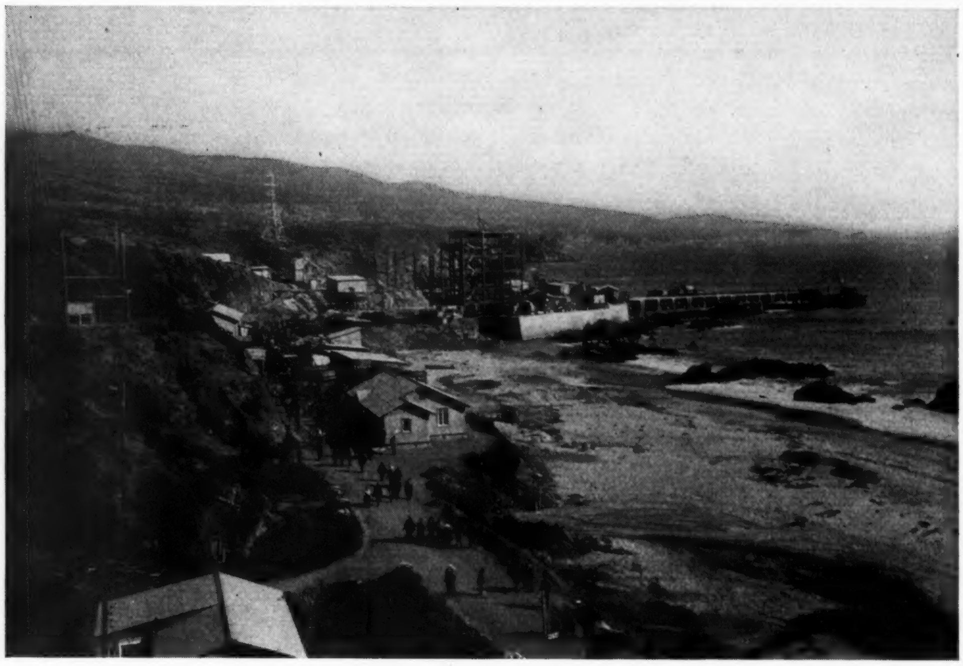
Coal Selection

Of all commodities, coal probably presents the greatest number of variable factors tending to complicate its proper selection. Because of the wide variation in characteristics of coals available in any particular market and the innumerable differences in firing equipment, furnace design and load conditions, the problem of economic coal purchasing often becomes most complex. In the absence of any standard by which one can judge his own coal buying, the only safeguard for the industrial consumer is to have available the maximum of reliable information on the qualities of all available coals on the market and on the engineering limitations of his plant, as well as adequate technical knowledge and experience to translate the facts into effective decisions as each situation arises.

One of the peculiarities of industrial coal buying is that the relatively small cost of providing adequate control and direction is visible, whereas the much greater cost of falling short of the best coal buying decisions is invisible. The larger the plant the greater this ratio of invisible to visible costs becomes. This applies not alone to the cost of fuel per thousand pounds of steam produced but also to maintenance, ability to carry load, outages and ease of operation. Purchasing agents and operating engineers, despite the fact that they are required to devote at least ninety-five per cent of their time to other duties, are often expected somehow to acquire a depth of experience and a breadth of factual data concerning coal, which, of course, is impossible. As in the case of feedwater treatment, this is a problem for the specialist. Some large companies, such as utilities and steel plants, which burn vast quantities of coal per year, often have such specialists on their engineering staffs, but the average industrial will usually find it advantageous to seek competent advice on such problems from without its organization.

During the past few years, both the level of coal prices and the pattern of price relationships among competing coals have at times been subject to serious disturbances, as a result of the attempts to provide governmental control of bituminous coal prices. In one form or another, this influence on coal prices may be expected to continue for some time in the future. Such conditions render comprehensive and exact methods of controlling coal buying both expedient and profitable.

Laguna Verde Generating Station in Chile



By LOUISE MANN[1]

Fig. 1—General view of Laguna Verde Station during early construction, showing topography of surrounding country

This new steam station of the Compania Chilena de Electricidad Ltda. is situated on the coast about six miles from Valparaiso and contains two 144,600-lb per hr stoker-fired boilers supplying steam at 375 lb, 765 F to a 22,500-kw turbine-generator. The steam generating equipment is of American manufacture and the turbine-generator of German make. The author discusses the economic considerations leading up to the design and location of this plant, the exchange situation involved in the purchase of equipment, the policy of the Chilean Government as regards power development and fuel supply, the local labor situation and the special type of building construction adopted to guard against earthquake shocks.

THE new steam-electric generating station of the Cia Chilena Electricidad Limitada at Laguna Verde, near Valparaiso, Chile, is nearing completion, construction having proceeded without interruption by the recent earthquake, as its location was not in the region most affected. Initial operation is scheduled for this spring.

Designed to withstand the worst earthquake shocks ever registered, the station building is of steel framework, covered with corrugated asbestos and having a stub stack on the roof. These features are in accordance with the Valparaiso building code devised to meet such contingencies.

The installed generating capacity of the company's system is over 215,000 kw and the new station will add 22,500 kw, initially. It is of unit design and further increases in capacity, according to present plans, would be in similar units of building, boilers, turbine and auxiliaries.

The present building contains two Combustion Engineering three-drum boilers, each of 144,600 lb per hr capacity with steam conditions of 375 lb pressure and 765 F total steam temperature. Elesco economizers are contained within the settings. These units are fired with C.E. forced-draft chain grate stokers and the furnaces are water cooled. Feedwater is treated by a zeolite process and a deaerating heater is provided. All fresh water for boiler makeup and service requirements is brought over a mile, through a 24-in. pipe line, from the company's hydroelectric plant at El Sauce; two large storage reservoirs being provided at the Laguna Verde end of the line.

The coal-handling facilities consist of a heavy concrete coal dock and aerial tramway from the dock to the station and to storage, a coal silo and a bucket elevator, a drag scraper system for stocking and reclaiming the coal and crushing equipment to permit purchase of run-of-mine coal, if desired.

Construction Features

Inasmuch as Chile produces no steel, most of its buildings are of concrete, a type of construction in which Chilean constructors and labor are very proficient. While consideration was given to reinforced concrete for the power station, a steel framework was selected to provide protection against earthquake shocks and for

[1] Louise Mann is the author of numerous articles of an economic nature on conditions and undertakings in Central and South American countries, including a recent series in *Public Utilities Fortnightly* on utility policies in several of the South American republics. Material for the present article was collected during a recent visit to this new station during its construction.

certain other reasons. All the building steel had to be imported and was fabricated in Chile with local labor, a fabricating plant being set up at Laguna Verde by Heiremans Hnos for this purpose. Some difficulty was experienced in meeting the construction schedule owing to the inability of the fabricator to secure adequate help that was experienced in the layout and fabrication of the substantial quantity of steel involved in this job.

Construction of the coal dock presented the greatest difficulty. Heavy seas rising at unfortunate moments wrecked two of the large circular steel-sheet piping caissons before they could be permanently filled. The concrete causeway from shore to the first inshore caisson and this caisson itself, however, were completed to permit unloading heavy equipment from barges, by means of which equipment was transported from Valparaiso. As the crane provided for coal unloading was not designed for the heavy weights involved in handling some of the equipment, a special marine crane on a barge was brought down from one of the northern ports of Chile to transfer the turbine, boiler drums and other heavy lift equipment to the dock. In spite of almost continuous ground swells this rather dangerous part of the unloading was effected without mishap.

Owing to many sharp turns and steep grades in the access road, it was deemed unwise to attempt transportation of large and heavy pieces overland to the site. However, a slide was provided down the side of the canyon to permit bringing in steel shapes and other bulky material should the sea make it impossible to unload from barges as material was required.

Importation of Machinery

In purchasing the equipment, three factors were considered, namely, the overall price, delivery and exchange. Prompt delivery, as well as price and certain other considerations, played an important part in the selection of the boilers. On the other hand, the turbine-generator set was purchased from A.E.G. in Germany, not only because this company's equipment was the lowest in overall cost and delivery was satisfactory, but because the Germans would accept payment in Chilean pesos, the currency in which all of the Company's revenue is derived. Other large items of equipment were also purchased from European concerns for the same reason.

Germany especially has an advantage in this market, because, other factors of price being equal, the compensation mark sells in Chile at a discount of 20 per cent, thus giving German goods an export subsidy of 20 per cent over competing goods in Chile, and sometimes as high as 30 to 50 per cent in other countries with which Germany has barter trade agreements.

Since Germany is short of many of the commodities which Chile exports, such as agricultural products, nitrate, copper and wool, the Central Bank of Chile has a tendency to become overloaded with compensation marks, causing a constant pressure for the admission of German goods into Chile.

On the other hand, goods imported by Chile from the United States must be paid for with internationally acceptable foreign exchange or gold. Practically the only large supply of exchange comes from the exports of the North American-owned copper companies. The government buys this exchange at 19.37 pesos to the dollar and sells it to importers for 25 pesos to the dollar. The ensuing profit is authorized to be spent for armaments at the rate of $5,000,000 a year for ten years.

The result of this transaction is that importers of goods from the United States not only have to pay more for their exchange but the supply of exchange is further limited by the amount withdrawn for the purchase of armaments. The profits from the nitrate and iodine corporations are earmarked for external bond service, so that this source of exchange is entirely eliminated.

Consequently, a quota restriction had to be imposed last year upon the importation of automobiles and radios into Chile. Furthermore, no authorization is being given to send dividends or profits out of the country, and sometimes difficulty is experienced in obtaining exchange permits for the payment of bond interest.

Under the terms of the Ross-Calder Agreement, the Chilean Government promises to provide all the necessary foreign exchange for buildings and equipment for the Laguna Verde power plant.

History of the Development

The Compania Chilena de Electricidad, Ltda., is the Chilean subsidiary of the American and Foreign Power Company. As a result of its activity in fostering the greater utilization of electric energy, for home uses

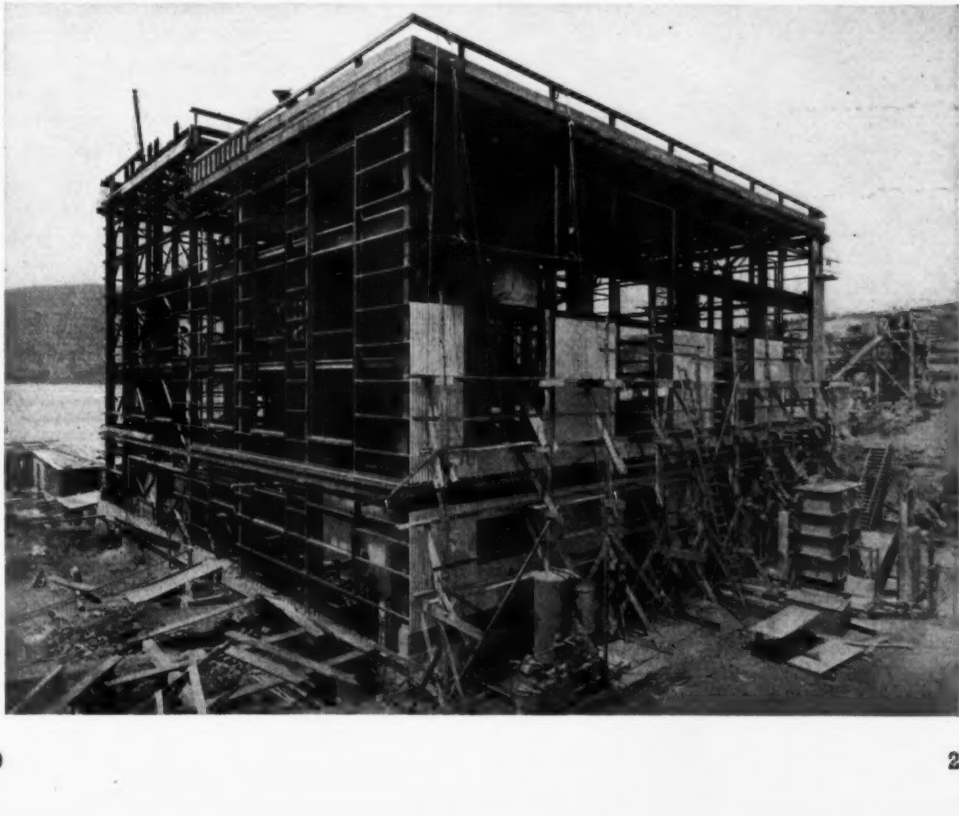


Fig. 2—Close-up view of building, showing asbestos siding in process of erection

as well as industrial purposes, the load continued to grow with only a slight recession in 1931 and 1932. Industrial users of electric energy were quick to realize the many advantages offered by the Company in the very cheap and thoroughly dependable source of energy to the extent that practically no industrial concern of any size has installed its own generating station within the last ten years. In this way the Company has contributed enormously to the industrial development of Chile as well as to the greater comfort of the small home owners.

The necessity for installation of additional capacity was recognized in 1931, and planning initiated to this end. The economic crisis of the early thirties slowed

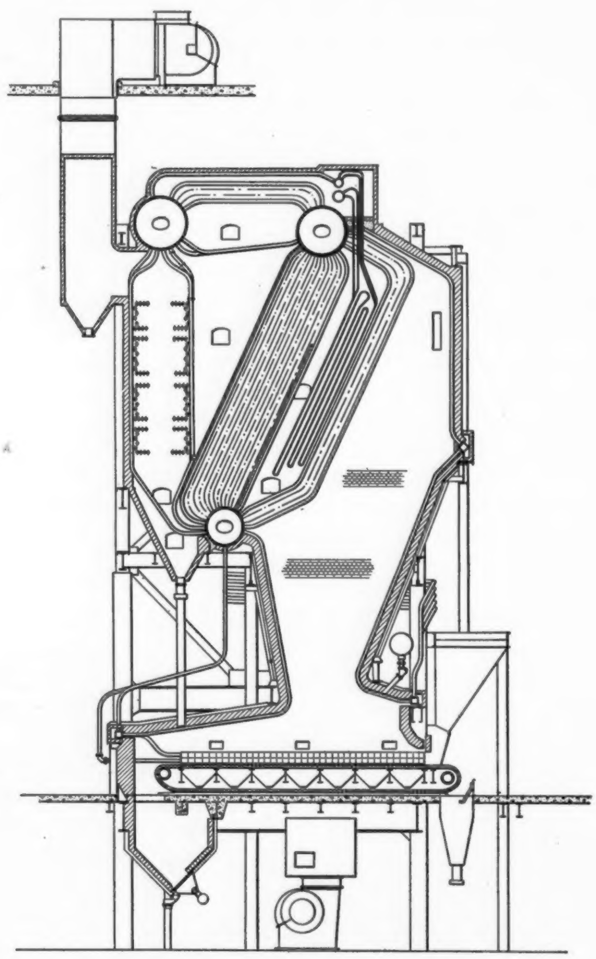


Fig. 3—Section through steam generating unit

the growth of demand on the Company's system for several years, and also rendered financing of the project difficult.

In 1935, however, under the Ross-Calder Agreement, construction of the new plant was expressly stipulated, the figure of 30,000,000 pesos being taken as an approximate minimum cost of the development; but this figure was not based on any detailed estimates. Design of the new station was initiated immediately. In the meantime, in the winter of 1937, the anticipated shortage of electricity developed, and street lighting in Valparaiso had to be curtailed an hour a day. By this time actual construction of the plant was already under way.

Land for the station had been purchased in 1931, and a sea wall constructed as a protection against the most severe storms of which there were any records. Upon preparation of detailed estimates it was found that the complete development would cost something in excess of 50,000,000 pesos.

Type of Station

Before deciding to build the steam-electric station at Laguna Verde, Cia. Chilena considered carefully the alternative of a hydro station, since it owns water rights on several streams.

A diesel station was out of the question, due to the fact that all fuel would have had to be imported. Consequently, the heavy duty on imported petroleum and the serious shortage of foreign exchange to cover imports, prevented this type of plant from being seriously considered.

Most of the energy generated in Chile is by hydro stations, except in the north where there is little precipitation. The terrain is fairly well suited to hydro generation, on account of the steeply sloping mountainsides that characterize the Chilean topography. Throughout the central portion of Chile all rivers rise in the heights of the Andean Range and are fed almost entirely by melting snow and ice. As a result, stream flows are greatest during the warmer months of the year. On the other hand, the load supplied by Cia. Chilena is greatest during the winter months when generating capacity of hydro stations is substantially reduced. Both the steepness of the mountain slopes and the geological newness of the Andes make it almost impossible to store sufficient water to carry stations over the low river flow period.

Since a majority of Cia. Chilena's capacity was in hydro, the foregoing and other factors contributed to its decision to build a steam station, following the generally accepted practice of large electric utilities in all parts of the world in installing thermal capacity to back up hydro capacity.

Location of Station

For economical operation a steam station has the fundamental requirement of accessibility to fuel supply and to water for cooling and boiler makeup. Before selecting Laguna Verde, a number of sites were carefully studied by engineers and consultants brought there for the purpose. Inland sites were eliminated due to limitation of water supply or difficulty of bringing in fuel. The logical location for the plant was deemed to be on the seacoast, and Laguna Verde, having a plentiful supply of cooling water and being close to the coal mines and to the Company's system, was selected from among a number of sites.

There are no natural harbors on the West Coast of South America, and protected anchorages now exist only at Valparaiso, San Antonio and Callao. These protections have been secured only at heavy expense and after several years of construction work. It is the universal practice of all shippers, particularly the copper and nitrate producers, to load in the open roadstead from lighters.

The Laguna Verde site is located about 6 miles due south of Valparaiso on a small cove surrounded by low hills of the coastal range; see Fig. 1. The station is protected from the prevailing south winds by a rocky promontory, although the bay is open to heavy ground swells and to

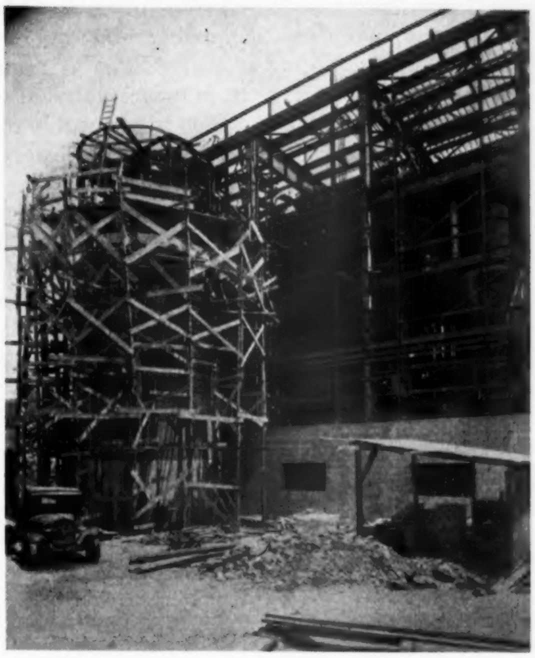


Fig. 4—Erecting steel housing over silo

such storms as may arise from the north and northwest. Due, however, to the fact that fairly calm weather is experienced during the majority of months of the year, unloading of fuel can be effected without difficulty in the accepted manner, namely, from steamers moving directly from the mines to lighters and thence to the Company's coal conveyor on the dock to storage.

Fuel Used

Chilean-mined coal should be ample for all the country's industrial needs, besides which there are vast undeveloped resources. In 1937, however, the demand for coal resulting from increased business activity began to crowd the present mining and transportation facilities of the larger mines, and by 1938 the situation was becoming serious. No capital was available for further development, the Chilean intercoastal steamships were feeling pinched, and industrial plants clamored for the elimination of the duty on imported coal. Recently, the situation has been slightly alleviated by the tapering off of the rapid increase in industrial activity.

The Department of State Railways, which includes the steamships, has the first claim on the Chilean coal supply. Industrial concerns under contract, including the Cia. Chilena, are served next, and even they are likely to experience trouble in the event of a shortage.

At present the high duty makes the cost of imported coal prohibitive, even if exchange were to be available for its purchase, which it is not. Should there ever arise a serious shortage of this fuel, it is felt that a reduction of the high tariff would quickly restore a satisfactory balance of supply and demand. National coal is of a fairly good quality, has a good thermal value and the ash and sulphur content is not excessive. Run-of-mine coal has a heating value of 12,550 Btu to 13,431 Btu per lb and slack coal about 11,060 to 12,300 Btu.

The Laguna Verde Station is designed for use of either run-of-mine or slack coal as the current conditions may require. Contracts for supply of coal from the mines as well as for transportation and lighterage to the Company's dock have been arranged, thus assuring adequate fuel supply for an extended period.

An affiliated company of Cia. Chilena owns a coal field and mine in the south, but output has been limited to use in steam stations in other parts of the system. It is unlikely that further general production of coal will take place, because private national capital prefers first mortgages yielding from 10 to 12 per cent, and no government capital is available.

Although Chile is geologically suited for the production of oil, the same lack of capital has impeded its discovery and development. Government policy not only does not wish foreign financial interests to obtain control of the Chilean oil industry, thereby preventing a situation similar to that of Mexico, but it also wishes to keep the control for itself as a social measure, and declines to permit oil to be developed even by private Chilean capital. Since it is able to appropriate only 3,000,000 pesos per year (about $120,000) for exploratory drilling, no commercial results have as yet been achieved.

Labor Conditions

Construction of the station has been carried out entirely with Chilean labor working under the direct guidance of five North Americans and the supervision of the Company's local engineering staff, some of which are also Chileans. Nationalistic labor laws in Chile, as in many other countries, render it difficult to bring in foreigners, unless it can be shown that there are no Chileans available for such work.

In the construction of Laguna Verde it was deemed necessary to bring in only the superintendent, resident engineer, boiler erector, master mechanic and electrical superintendent, all of whom are from the United States. The turbine erector, furnished by the turbine company, was a German in the country at the time.

Construction labor throughout Chile is of the floating

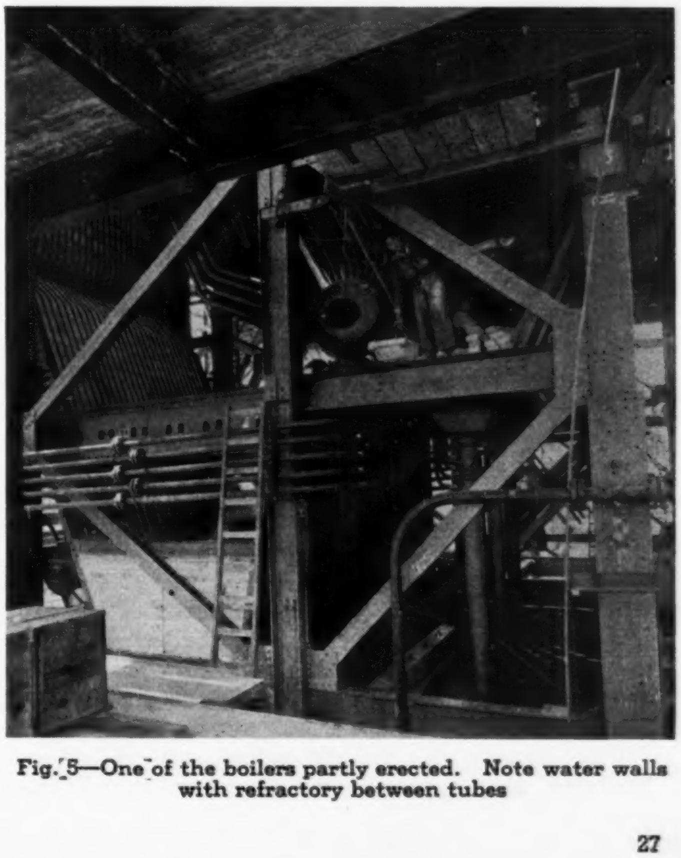


Fig. 5—One of the boilers partly erected. Note water walls with refractory between tubes

type, following construction work much the same as itinerant harvest labor in the United States. It is preponderantly radical in its political viewpoint and is entirely motivated by sindicatos or labor unions. Chilean workmen are not highly efficient, but are quick to learn. On a cost per man-hour basis Chilean labor is not as effective as labor in the United States.

In order to eliminate disturbances and protect the workmen themselves, the Government declared the Laguna Verde zone dry. It enforces prohibition and preserves order with a detachment of carabineros at the camp.

The Company has built stores, a school and residences for teachers at the construction camp, to be maintained at its own expense.

Government Policy

The public utility policy of both the Chilean government and the Cia. Chilena is to furnish a plentiful supply of cheap electric power for the people. In this program they have been handicapped by the depreciation of the peso from about 12 cents United States currency in 1929, when most of the investment was made, to 4 cents at the present time. Consequently, the machinery imported for new construction has to be paid for at world prices, while revenues are received in the depreciated currency.

Despite this handicap, as well as the other difficulties enumerated above, such as earthquakes, storms and potential shortage of fuel, at the present time the Government and the Company are cordially coöperating, and the Laguna Verde Power Plant is nearing completion.

Fouling and Corrosion of Air Heaters

In the 1938 E.E.I. Prime Movers Report on "Boilers, Superheaters, Economizers, Air Heaters and Piping" which has just been issued, comments are made on the fouling and corrosion of air heaters. Much of the data collected by the Committee are corroborative of conclusions set forth in Bulletin No. 228 of the University of Illinois Experiment Station on "The Corrosion of Power Plant Equipment by Flue Gases," issued in 1931. These were that:

1. Such troubles usually increase as the metal temperature decreases below 300 F, above which temperature troubles are slight, if any.
2. Sulphur content of the coal and dust burden in the flue gases have determining effects.
3. The dew-point of flue gases containing traces of sulphuric acid vapor is higher in comparison to the dew-point when only water vapor is present.
4. Deposits of hygroscopic materials, such as dust and ferric sulphate, cause moisture films at gas temperatures as much as 50 to 75 F above the dew-point of the flue gases.

The average operating temperatures of outlet gases, indicated in the data collected by the Committee, varied from 200 to 500 F. Assuming an inlet air temperature of 100 F, the clean metal temperatures would vary from 150 to 300 F; if these be taken as the mean of the air and gas temperatures. Measured dew-points were found to be in the range of 100 to 250 F, the higher values occurring with coals of a high sulphur content. Therefore, it is apparent that air heaters now in use have metal temperatures that correspond to possible gas dew-points, irrespective of the further effect of hygroscopic deposits in promoting moisture films at temperatures above the dew-point. It is further obvious that deposits form a heat insulation which is permeable to gas, so that the dirty metal temperature may be lower than the mean of the gas and air temperatures.

The formation of deposits on air heaters, however, does not necessarily result in corrosion, if other conditions are favorable. This is illustrated by one installation where a $^1/_8$-in. to $^1/_4$-in. coating develops in air-heater tubes during a year's run. This is easily removed and the tubes show no evidence of corrosion. The exit gas temperature in this particular case varies from 450 to 550 F.

Quoting from the earlier bulletin, fly ash from pulverized coal firing is usually lower in sulphur than that from stokers; the sulphuric acid vapor concentration in stack gases from pulverized coal firing is about 70 per cent less than that from the same coal burned on stokers; and hygroscopic sulphate deposits are less likely to occur with pulverized coal firing than with stokers. It seems from the data now at hand that fouling can be expected when burning a high-sulphur pyritic coal on stokers when the outlet gas temperature is in the usual range. Instances were reported in which no appreciable fouling was experienced when burning pulverized coal or gas; and when a change was made to fuel oil having a sulphuric content of 2.5 per cent, fouling quickly appeared and materially decreased the life of the air-heater elements.

Various expedients were reported for reducing the fouling and corrosion of air heaters. These included improvement of furnace conditions to decrease the dust loading of the flue gases; the installation of baffles to give a uniform air distribution or to deflect a greater volume of flue gases toward the coldest portion of the air inlet; the prevention of cold air leakage; insulation of extremities of surfaces that receive an excessive amount of cooling from incoming air; the installation of sectional elements to reduce renewal costs; reversal of elements; the use of alloy elements to resist corrosion; recirculation of part of the hot air; rapping of elements in regenerative heaters to dislodge deposits; special washing methods to completely remove deposits which might promote hygroscopic action; and discontinuance of the use of steam soot blowers. Bends in heater tubes have been found to promote the formation of deposits.

The life of air heater elements, as reported, varies from two to over ten years. Periodic intensive cleaning is generally practiced and may consist of the removal and wire-brushing of plates, drilling with tube cleaners, soaking with a solution of soda or caustic and subsequent flushing.

The Committee concludes, from the data submitted, that it is frequently considered advisable to choose an outlet gas temperature which may be expected to cause some degree of fouling and corrosion. Only a few cases were reported where the gas temperature was high enough to prevent gradual corrosion, or to prevent more rapid corrosion if adhering deposits are not periodically removed by cleaning the gas side of the heaters. The lack of proper gas temperature for the existing fuel and combustion conditions appears to be almost entirely the cause of accelerated troubles from fouling and corrosion.

JUDGING COAL VALUES

By G. B. GOULD

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The following observations, based on the author's long experience as a fuel consultant, emphasize the great diversity in coal-buying problems; indicate the steps necessary for intelligent coal selection; discuss the value of preliminary appraisals and the variables that affect such appraisals; and point out the importance of employing a heat balance analysis to guard against misinterpretation of comparative trials.

COAL buying is never a matter of routine, unless it has fallen into a condition of stagnation, or is treated with indifference, due to under-estimation of its effect upon steam costs. It involves a continuous series of decisions, of choosing among possible alternatives and the accuracy of these decisions has an important effect on the cost of steam. Even the continuous buying of the same coal represents a continuous series of decisions *not* to buy some one of many competing products.

The accuracy with which coal-buying decisions are made is not capable of measurement, while a change in operating efficiency not only can be detected but also measured against an established standard of performance. The effect of a miscalculation in coal buying is almost sure to escape notice, except when it leads to very unsatisfactory operating conditions.

Every coal-buying decision has to be judged in the light of the circumstances at the time the decision was made. The level of coal prices changes, the relationship in prices among competing coals changes, the quality of coals changes, plant requirements vary with changing rates of manufacturing activity, and finally, the prospect of future conditions in the coal market is never the same on any two dates. In addition to all this, if there were a better value than the one chosen, which was either not known to the buyer, or not recognized by him at the time, the loss is obviously unseen.

No Two Coal-Buying Problems Exactly Alike

Even if the level of prices, and the price relationships among different coals were constant, the appraisal of relative coal values for a particular plant would, by no means, be a simple matter. Coals produced in various mines differ in so many ways, due to differences in the coal itself, in the conditions in the mine, in mine equipment and in management and personnel, that there are scarcely any two coals which are precisely alike.

Nor are there any two industrial steam plants precisely alike. Plants that are operating today have been built at different times over the past twenty or thirty years, during which period there have been continuous changes in the design of coal burning equipment. These plants have been designed by different people, each of whom has had his own ideas of what was the thing to do at the time. Many of these plants were really not designed at all, but are merely an assembly of parts picked up here and there. Some have become what they are through a series of piecemeal alterations and additions. Each has its own characteristic load requirements (which incidentally may differ considerably from what the plant was originally built for); and no two are alike in the competence, experience and temperament of the men who operate them.

All these affect the performance of the plant as influenced by some one or two, or a combination of several, properties of the coal. The coal buyer has to take this combination of limiting conditions, whatever it may be, and out of a hundred or two hundred, or even as many as five hundred coals, choose the one or two which will result in the lowest steam cost, *considering the relative prices at the time each decision is made.*

Too Much Undigested Information Makes Coal Buying Difficult

Each coal-buying decision is obviously a mental process, involving some element of judgment. It may be based upon much engineering data, skillfully related, which leaves only the finer points in the field of pure judgment; or it may be little more than a pure guess, hastily arrived at, and based on little or no real information. Most industrial coal buying, of course, falls somewhere between these extremes.

During the past quarter of a century, the rate at which fragmentary and unrelated data (of widely varying degrees of reliability) on coal qualities has been accumulated and the rate at which power plant instruments and laboratory indices have been developed, has run ahead of the ability of most power plant operators and coal buyers to interpret or to apply with accurate discrimination. A state of almost total ignorance of coal and its performance has been replaced (temporarily) by a bewildering mass of undigested fragments of technical information, which can be either very misleading, or very helpful, depending upon the experience and technical knowledge of the person who tries to use it. There is some question as to whether the conscientious coal buyer is not in a more difficult position today than he was twenty-five years ago. It is well to recognize that it is much easier to get facts in the form of scientific measurements of one kind or another than it is to learn how to use them.

In appraising relative coal values, it is important to separate the numerous measurements and indices and

the physical effects to which they relate into two distinct groups, which for lack of better labels, may be termed "quantitative" and "qualitative."

One must distinguish clearly between those properties of coal that are essentially *qualitative*, and those which represent or directly affect the *quantity* of energy. Correspondingly, distinction should be made in the use of coal between the quantity of energy extracted from it, and the collateral effects of its use which are favorable or unfavorable to the satisfactory functioning of the plant. This should be done in one's mind, even though it is not always possible to keep them separated completely in practice.

Quantities and Their Measurement

Coal is bought for the energy that can be extracted from it. The quantity of energy in the coal is determined by sampling and laboratory testing. The quantity of energy derived from it is determined by measuring the quantity of steam generated, which at any given pressure and temperature has a known heat value. The strictly quantitative measurements are (1), the weight of the coal; (2), its heat value per pound; (3), the weight of steam; (4), its heat value per pound; and (5), the cost of the coal. The percentages of ash and moisture in the coal have indirect quantitative significance, especially the moisture, since this can change from time to time, and the amount present at the time the coal is weighed must be known, if the coal weights are to be used accurately.

If coals differed only in their Btu value, their relative values for all consumers could be arrived at by a simple mathematical calculation. Unfortunately, they are not alike, and it is the *qualitative* differences in coals which make some totally unsuited to certain plants. They modify the percentage of the inherent energy value that can be extracted, and make the appraisal of relative coal values so difficult.

Coal Qualities and Their Effects

Coals vary in seven important known chemical or physical properties for which there are methods of identification and measurement in the laboratory. These are the per cent of volatile, per cent of sulphur, softening temperature of the ash, chemical composition of the ash, size distribution, friability (or size stability) and grindability. Another important characteristic in which they may vary is the nature of the coke formed. This so far has defied all attempts at definition, or description beyond such general terms as "strongly coking," "weakly coking," "non-coking" and "free-burning." The per cent of moisture and ash, already referred to as having quantitative significance, may affect the fuel bed or furnace conditions, and so have qualitative significance as well. The ultimate analysis breaks the coal down into percentages of the primary chemical elements, hydrogen, carbon, oxygen and nitrogen, without disclosing how they are combined. This analysis is necessary for the calculations entering into the analysis of boiler and furnace performance.

Some of these laboratory measurements can be further refined, when necessary. For example, sulphur may be divided into organic and pyritic sulphur and moisture into surface and inherent moisture. The softening temperature of the ash represents the temperature at which the *whole* ash of the coal, as a mixture, softens, and is an index which serves most purposes. But nearly all coal is a mixture of different materials which can be physically separated, and the ash in these different fractions may soften at temperatures several hundred degrees apart.

All of these properties of coal relate to effects in using the coal, such as slagging, clinkering, smoke, corrosion, dust, handling and storing qualities; also, the nature of the fuel bed. And these, in turn, are translated into terms of plant capacity, reliability of service, cost of maintenance, labor cost of coal handling or plant operation, losses due to spontaneous combustion, conditions objectionable in the plant or in the community, such as dust and smoke, and the efficiency of the boiler and furnace.

Now it can be seen that most of these effects have no direct relation to, or influence upon, the quantitative measurements. Except in so far as they can be shown to have a direct influence upon the quantity of energy recovered, these effects should be evaluated separately. One of the most serious pitfalls in appraising relative coal values lies in the fact that coals do vary in such a complex way, and it is *assumed* that variations in the quantitative results from comparative plant trials are due to unidentified effects upon plant performance of some of these purely qualitative characteristics. This is a dangerous assumption, and one which leads to many coal buying miscalculations.

Four Steps in Coal Selection

Coal selection should proceed in four steps. These are:

1. Fuel-engineering analysis of the plant.
2. Qualitative selection of those coals suited to the requirements of the plant.
3. Preliminary value appraisal to eliminate all but best values.
4. Final quantitative valuation.

Obviously, since coal selection is individual to each plant, the first essential is a fuel-engineering analysis of the plant, to determine its limitations in terms of those specific chemical and physical properties, which a coal must have to provide satisfactory operation. These limitations may be introduced anywhere between the point where the coal is unloaded and the stack. Possibly the coal is dropped a considerable distance at unloading, and dust may be objectionable for a variety of reasons. Freezing of coal in cars or in storage may be a factor. Pulverizer capacity, grate area or furnace volume must be considered in relation to the required maximum rate of steam generation. Draft limitations have a bearing on coal selection. The adaptibility and resourcefulness of the operating force must be considered. Smoke restrictions must be complied with. These are some of the many factors which enter into such an analysis. They can all be related to the chemical and physical properties of the coals available.

Some plant limitations on coal selection are only a matter of avoiding needless unsatisfactory trials by well-informed qualitative selection, and of simplifying the later steps in coal selection. Other limitations can only be met by confining one's coal buying to certain narrowly specified types of coal which bring a premium in the market. Such limitations actually cost money. They

should be identified for what they are and their cost recognized.

A limitation on coal buying also costs real money when it is supposed to exist, but actually does not. This sometimes happens due to the misinterpretation of the results of an unsatisfactory trial of one coal, by assigning incorrectly the cause of the trouble to some properties of that coal, thus ruling out all other coals having those same characteristics. It is dangerous to generalize about coal limitations from the experience with any one coal, because of the effect of the *combinations* of properties. It is much safer to start with an analysis of the plant. The conclusions from such an analysis can always be checked against experience with coals having known combinations of properties. But it is unwise to work backwards, trying to deduce plant limitations from experience with a few coals, the exact properties of which may not have been accurately known.

There is a widely held, but mistaken idea that there is an "ideal" analysis of coal for each plant, one that specifies precisely each of the items. The characteristics of a plant determine certain limits, such as "not more than" such and such a per cent of ash, or volatile or sulphur, or "not less than" a specified softening temperature of ash or size. But even these limits must be varied at times in relation to other properties of the coal, because of the inter-relation of two or more characteristics. For example, a size limitation may call for $1^1/_4$-in. nut-slack in a hard structure coal, while a larger size, or a double-screened size would be necessary in a more friable coal. A limit on the minimum softening temperature of ash will vary both with the size and coking characteristics of the coal. Some of the effects of low grindability may be offset by higher percentage of volatile.

Qualitative Coal Selection

Having determined by analysis of the plant what its coal buying limitations are, in terms of the properties of coal, qualitative coal selection can proceed by eliminating from the coals which are available on a competitive basis, those which will be definitely unsatisfactory and unsuitable at any price. This, of course, presupposes an accurate knowledge of the average quality, and the variations in quality of each coal.

There will usually be a group of coals, which while not definitely unsuitable, will have some less important disqualifying characteristics, that could be tolerated, if relative prices offered some compensating economy, as compared with the residual group which is known to have all of the desirable qualities. These need to be kept in view at least for preliminary valuation.

Every thoughtful coal buyer, consciously or unconsciously, goes through some such primary step of coal selection. How completely the available coals have been covered, and how near to the ultimate selection the process has been carried, depends upon the accuracy of the basic plant analysis, and the amount of reliable data available on the individual coals. The more completely the whole field can be canvassed, and the farther the early stages of selection are carried, the simpler, the more quickly adaptable and the more economical will be the remaining steps in coal buying.

Through the primary stage of selection, coals are included or excluded wholly upon the basis of their qualitative characteristics and their effects upon the operation of the particular plant which, in turn, is predicated upon the analysis of the plant. Only in the later stages of coal selection do the purely quantitative measures come into play.

If this primary, or qualitative, selection cannot be made to any great extent, because of inadequate analysis of the plant, or for lack of sufficient information on the quality of individual coals, then the process becomes one of random trials, and qualitative effects and the quantitative values become confusingly mingled. Of course, even under the most favorable conditions, there is usually a borderline group of coals, the qualitative advantages or disadvantages of which have to be balanced against the relative values determined from the Btu, price and plant efficiency. But by proceeding in this way the coals which need to be more precisely evaluated are reduced to a small number, and the qualitative merits or demerits are consciously balanced against a determined or determinable money stake.

Preliminary Value Appraisal

At this point relative prices enter the picture. If one has a fairly wide and detailed knowledge of the price pattern over the whole field, the coals which have survived the primary stage of selection can be further reduced by a rough cut, based on this knowledge. Certain classes of coals, at certain times, for delivery at certain destinations may be at a competitive disadvantage due to the general price relationships existing then. At many points, however, these relationships are not continuously exclusive of any group of coals, so that this step must be made, if at all, on the basis of the *current* price pattern.

The remaining coals, which have not been eliminated for one reason or another, are ready for closer examination, on the basis of specific quoted prices for each. When these prices have been received, the two groups of surviving coals (those having all the desired properties, and those only partially disqualified) can be tentatively evaluated on the basis of their relative heat values. There will probably be no more than fifteen or twenty coals still under consideration at this stage. The best one or two values among the completely qualified coals are identified. These coals will be perfectly satisfactory, and among their own group are to be preferred. The whole process of coal selection, up to this point, can be carried out without any plant trials, if the quality of all available coals is known and if the plant itself has been properly analyzed.

The remaining question is, do any of the other coals, which have or may have some slight disqualifying characteristics, offer a margin of *extra* value, which would more than compensate for some extra labor in handling, for closer attention to the fires, for slightly lower efficiency or possibly for a little more dust than we would like to have. In fact, the decision has now been reduced to such a fine point, that a full-scale plant trial may be needed for final evaluation. Some of the finer points of discrimination might be classed as "intangibles," but they may, nevertheless, be real to the men operating or managing the plant. They alone can decide.

There are many advantages to this method of coal selection by which a large number of coals are examined before any attempt is made to arrive at purely quantitative valuations. For one thing, only a small number of

coals are left to pass the final examination, thus permitting the closest scrutiny without undue expense or delay. The few coals that remain have either passed through this sorting process without any reservation as to their suitability, or they have been retained for final quantitative valuation with certain recognized reservations as to certain characteristics, the effect of which in operation can be foreseen and particularly observed. Also, the whole field can be quickly re-examined at any time, when prices or other conditions change.

If skillfully done, this preliminary sorting, in addition to focusing the final stage of valuation upon a small number of coals, has the following practical advantages:

1. The risk of outage, or serious damage to combustion equipment or furnaces from random trials of unknown coals is eliminated.
2. The time and expense of trials of coals certain to be less satisfactory than the coal in use is avoided.
3. All the coals which can reach a given consuming point can be considered. The buyer can keep the entire market under review.
4. Coal buying becomes stabilized, but never stagnant, and is capable of almost instantaneous modification to changes in the price structure, in the quality of individual coals or in the plant requirements.

Assuming that an orderly process of elimination has been followed, there still remains to be determined whether there are undetected differences among the few close contenders, which will materially modify the fuel-engineering forecast. This calls for a full-scale trial in the plant, which will confirm or modify the expected fuel cost per unit of steam generated, and disclose any unforeseen qualitative defects.

Quantitative Values Often Misleading

Both the determination and use of quantitative values in coal buying differ from simple engineering observations which have to do with the quality of *individual lots of a material* or the performance of a steam generating unit at a specified time and under specific controlled conditions. This distinction is often overlooked.

A buyer of industrial coal is usually making a decision which will govern a series of shipments aggregating several thousand tons. An accurate choice among several competing coals depends upon an accurate estimate of what the plant will recover from each of them in terms of energy over a period of time.

Some buyers have thought that the necessary comparison of values could be made solely upon the basis of trial shipments of several coals. Each coal is used for a period of a few days, or possibly a few weeks. So many pounds of coal are fired, and so many pounds of water are evaporated. The ratio between the two, combined with the price, derived from each trial, gives an apparent measure of their relative values. The word *apparent* is used advisedly. The fact that the result of this procedure can be expressed as a single figure—"fuel cost per thousand pounds of steam," carried out to as many decimal places as the computer desires—leads to a very deceptive illusion of accuracy, which is responsible for more miscalculations of coal values than any other single thing.

If the performance of a boiler unit were affected only by the properties of the coal, it would be a simple matter to calculate relative fuel values by comparing the "evaporation per pound of coal" derived from the trial of several coals. The result would be as simple and conclusive as the weighing of two objects on a scale. Unfortunately, there are many variables in boiler operation which cause differences in performance from day to day, and from one period to another. These differences have to be taken into consideration and allowed for. Otherwise their effect on the results, which is often of greater magnitude than the real differences in fuel values, will be mistaken for them. This is a real danger, and one which is little recognized. Many plants are not even equipped with the necessary instruments to disclose these changes in operating conditions.

Variables That Affect Coal Value Appraisals

The quantitative measurements of coal values are, therefore, worth examining. The quality of coal from any mine is known to vary from shipment to shipment. The extent of this variation may be large or small, depending upon the mine, but it is always present as a source of error when the value of a coal is measured from a trial lot.

The percentage of moisture in the coal at the time it is weighed in to the boiler room varies with the weather conditions to which the particular lot has been subjected during transportation from the mines, while it is in storage and at any time it has been loaded, unloaded or handled in any way. Between two lots of coal, this may vary as much as 3 or 4 per cent. If undetermined, the result is a distortion of the apparent relative value derived from an evaporation test, which amounts, in terms of value per ton of coal, to 15 or 20 cents per ton. This is, of course, enough to completely conceal a favorable differential in value, which if undetected, can alone produce a miscalculation amounting to several thousand dollars over the period of a year.

And, finally, the evaporation figures obtained from a trial run, in addition to being influenced by the two sources of variation just mentioned, are subject to a most complex, and usually unrecognized, series of variables. These are inherent in boiler operation, and have no relation to the character or quality of the coal being used. The extent of these variations, independent of coal quality, is very widely overlooked. The evaporation per pound of coal in a given plant, *using the same coal,* may vary from one part of the week to another, from one week, or one month, or one season to another, by a greater amount, when translated into terms of value per ton of coal, than the true differences in value among competing coals.

The point is that the weight of coal fired, and the weight of steam generated during a certain period may be absolutely accurate observations, and still not provide an accurate or reliable index of the relative value of a coal, for purposes of coal selection.

One might jump to the conclusion from all this, that it is really not worth while to attempt to measure the relative values of competing coals; that one would be just about as likely to hit upon the best choice by buying from the coal salesman he likes best. The truth is that some coal buying decisions, based upon no measurements at all, are nearer the mark than others that are based upon partial and uncorrected data, which has all

the superficial appearance of exactness. But the odds are heavily against either method.

Good engineering is not scared off by the existence of variables in an equation. It is simply a matter of identifying these variables, measuring them and providing means of correcting for them, when they occur.

Correcting for Variations in Coal Quality

Variations in quality of one shipment of coal from the long time average quality for that coal can be allowed for. It is possible by sampling and laboratory testing to determine the quality of one lot of coal within satisfactory limits of accuracy. In order to allow for variations in quality from shipment to shipment, every trial lot should be sampled and tested in the laboratory. Any significant deviation from the average can be taken into account. No single sample of one lot of any coal is a sufficiently accurate basis for comparison of relative coal values. Accurate computations of relative coal values require the possession of an average of a series of samples of a number of shipments of each coal.

Much research in recent years, conducted in England, South Africa and the United States, has conclusively shown that laboratory test data of coal quality follow well-known statistical laws. One important result of this has been that we are able to use mass data on coal quality with a high degree of accuracy, and to allow for the deviations of individual tests of single lots with statistical precision.

The detection of significant variations from normal in the moisture content of coal is possible by comparing the percentage of moisture in a trial lot, with a year-round average for that type of coal. There is more general misunderstanding of what is a typical moisture percentage than there is concerning almost any other of the properties of coal, for the reason that a great majority of the laboratory coal tests, which are published or circulated for sales purposes, have been made upon partly dried-out samples. In fact, it is not uncommon for laboratories to omit entirely the determination of the moisture in the sample as it is received, but determine this only after the sample has been pulverized and divided down for the other laboratory tests. There are numerous uses for laboratory tests, for which the exact moisture content is not significant, and laboratory tests of this kind are often quoted in selling coal.

Obviously, the buyer, who is attempting to evaluate a coal by a trial of a shipment which happens to contain 2, 3 or 4 per cent more moisture than normal at the time it is weighed to the boilers, will have apparently used that much more coal. This must always be watched and allowed for, when evaporation figures are being used to arrive at relative coal values.

Correcting for Variations in Boiler Performance

The way the great majority of industrial steam plants are operated, variations in boiler performance, independent of the quality of coal being used and important as they are, cannot be detected. Being unseen, their existence is usually not even suspected, and the result is that the whole difference in evaporation per pound of coal, between trials of two or more coals, is supposed to represent differences in coal values.

This can be guarded against only by the use of the heat balance. Accepted as the standard method of describing the performance of a boiler and furnace, the heat balance is an *absolute* necessity as a method of interpreting comparative trials of two or more coals. When used for this purpose the conventional form of heat balance, prescribed in the boiler test codes, can be simplified by condensation and re-arrangement of the items as follows:

Loss of heat in dry flue gases	12.3%
Loss of heat in refuse	1.1%
Losses due to moisture and hydrogen	3.7%
Total measureable losses	17.1%
Heat absorbed in steam (efficiency)	78.8
Unaccounted for losses	4.1
	100.0%

Back of this simple summary of performance, there is, of course, additional data which is of great importance in interpreting the results of a trial of coal; the quality of the particular lot of coal as shown by the laboratory test, the evaporation per pound of coal, the CO_2, the exit temperature of the flue gases, steam pressure and temperature, temperature of feed-water, the rate of steam generation, etc.

The heat balance for any plant will fall into a pattern characteristic of the equipment and operating conditions of that plant. Therefore, if a trial run results in a normal distribution of the losses for that plant, and consequently a normal efficiency, but the particular lot of coal used during the trial deviates from its average quality, or from a normal per cent of moisture, it is a simple matter to correct the observed evaporation per pound of coal for these deviations. The heat balance has shown that the properties of the coal have not affected the quality of performance, and we are, therefore, justified in substituting the average quality of the coal for the quality of the single lot.

Heat Balance Control of Coal Buying Guards Against Misinterpretation of Comparative Trials

If, on the other hand, the quality of the trial shipment is closely in agreement with the average quality for that coal, and the percentage of moisture is normal, but the efficiency during the trial deviates substantially from that which is typical for the plant, the cause of this difference in performance can be traced from the particular class of losses, which will have necessarily deviated from the normal pattern.

It is by this means that the cause of those frequent and often large variations in evaporation, which result from changes in load, from differences in the cleanliness of boiler surfaces, from improper handling of the fires, or of draft regulation, can be separated from variations which are really chargeable to some property or combination of properties of the coal.

And, too, it is only by examination of the heat balance and its supporting data that one can guard against a series of trials becoming merely an experiment in finding a coal which best fits a set of fixed habits of the boiler room personnel. Boiler room methods are often the controlling factor in comparative trials, but this goes undetected unless performance is under heat balance control. Methods which have become too inflexible from custom to get the most out of coals that vary somewhat in their physical properties or methods which are too variable because uncontrolled, inject a random influence that can so modify the comparative evaporation figures as to make them meaningless. These things cannot

distort coal value comparisons, when the quality of plant performance during each trial is subject to heat balance analysis.

Heat Balance Analysis Avoids Futile Plant Trials

There is another distinct advantage which heat balance control gives to coal buying. Every plant has a determinable optimum heat balance, which is the best that plant can possibly do in the way of extracting energy from coal. Normally, the coal being used permits a close approximation to this best practicable performance. When this is true in a given case, it becomes possible to determine without trial, whether or not it is physically possible for another coal of known average quality at a stated price to bring about any reduction in the coal cost per unit of steam generation. Many trial purchases can be avoided by knowing when the physical limits of possibility will have to be exceeded in order to make some coal of better value than the coal in use.

When coal buying is fortified by fuel-engineering analysis of the plant and primary qualitative selection, and is kept under heat balance control, the whole process is simplified in two ways. The coals which are unsuitable for purely qualitative reasons are excluded in the primary stage of coal selection, and those which are suitable for qualitative reasons, but which cannot compete without exceeding the limits of physical possibility are eliminated by mathematical deduction. There are literally thousands of comparative coal trials every year, which engineering analyses would have shown to be obvious violations of predetermined qualitative limitations, or impossible of success without exceeding the plant's physical capacity to absorb heat. Fuel engineering guidance in coal buying aims to:

1. Keep the whole field of possible sources of supply under review.
2. To be able, without trials, to identify those coals which are certain to be objectionable for qualitative reasons.
3. To eliminate, without trial, qualitatively suitable coals, which cannot yield lower costs except by obtaining a quality of performance that is beyond the built-in limitations of the plant.
4. And thus to make coal buying simpler, more accurate, more economical and more quickly adaptable to changing conditions.

Coal buying is a job of finding one's way through a maze of confusing roads, many of which are not marked, and those that are, often have misleading signs. The destination (lowest practicable steam costs) is never a fixed point. Neither falling nor rising coal costs are a measure of skillful or unwise coal buying. Rising coal costs may go along with a masterly bit of coal buying, and falling costs may conceal the effects of very inept coal buying, simply because conditions in the market or in the plant which are beyond the control of the buyer happen to be dominant in determining the level of costs.

Single Boiler Meets Refinery Steam Requirements

By D. S. FRANK and J. M. AUGUSTUS
The Pure Oil Company

At the Toledo Refinery of The Pure Oil Company a new boiler plant has been constructed, housing a 65,000-lb per hr steam generating unit which provides steam for all process demands. Duplication of equipment was avoided by arrangements for an independent source of standby steam supply. Oil and refinery gas are burned, although provision has been made for burning pulverized coal should this be desirable in the future.

THE normal steam demand at the Toledo, Ohio, Refinery of The Pure Oil Company is around 50,000 lb per hr but occasionally reaches 65,000 lb. In summer it is slightly less. This steam was formerly obtained from another source but early in 1938 it was decided to erect a new boiler plant. Taking advantage of an agreement whereby standby steam service would be available from the former source during periods of cleaning or repair it was decided to install a single steam generating unit of adequate capacity to meet the full refinery requirements, thereby holding the investment per thousand pounds of steam to a minimum.

When designing the boiler house provision was made to permit the installation of a second boiler alongside the present unit should steam demands of the refinery increase. In this arrangement the back wall of the existing boiler forms part of the rear building wall and the back wall of the second unit would also form part of the rear building wall by removing the steel sash and windows shown in the exterior view, Fig. 1. This would permit easy installation of the second unit without expensive alterations to the building.

It will be noted that the induced-draft fan and stack are carried on a steel platform exterior to the building.

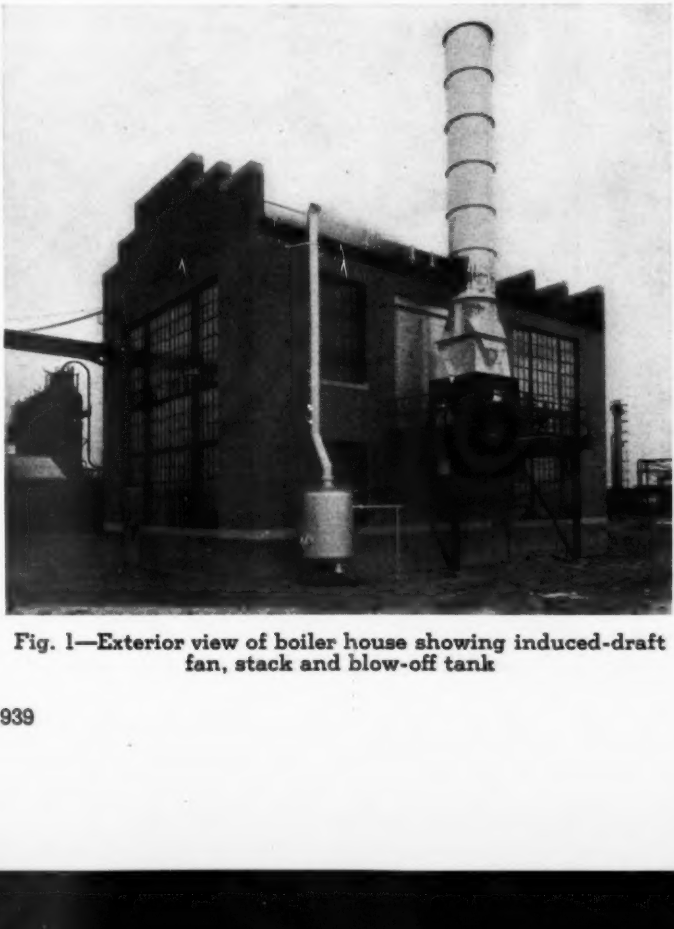

Fig. 1—Exterior view of boiler house showing induced-draft fan, stack and blow-off tank

Oil and refinery gas, fired separately or together, are the fuels burned at present. Refinery gas is burned when available and oil makes up any deficiency. However, the boiler was selected with a view to burning pulverized coal should future coal prices warrant. Although pulverizing equipment was not purchased, the furnace is proportioned for burning pulverized coal and combination burners have been installed. Also, an ash hopper has been provided.

The unit selected is a C-E two-drum, Type VU steam generator of 65,000 lb per hr capacity. Steam conditions are 150 lb operating pressure and 470 F total steam temperature, corresponding to approximately 100 deg superheat. This unit, which went into service last December, has to date produced in excess of 75,000 lb per hr for periods as long as two hours. It has a total of 7428 sq ft of heating surface distributed as follows: boiler 5325 sq ft, superheater 453 sq ft and water walls 1650 sq ft. No heat recovery surface is provided and the upper drum contains a steam washer of the C-E bubble type.

The furnace, which has a volume of 2375 cu ft, is completely water cooled with plain tubes on the front, sides and roof, backed by refractory of the Detrick supported type, independent of the water walls. The refractory, in turn, is backed by insulating brick and a steel casing.

Each of the two Type R burners, arranged one above the other, is capable of generating 40,000 lb of steam per hour when burning oil, refinery gas or pulverized coal. The oil nozzles are of the Enco steam-atomizing type with 80 lb oil pressure at the burners. A Fisher pilot-operated valve automatically varies the oil pressure with a variation in steam pressure in the main steam line to the refinery. This steam pressure is maintained within a range of less than one pound. The regulator also reduces the oil flow automatically when the operator chooses to burn refinery gas. He manually opens the 4-in. valves in the gas supply lines to the burners an amount depending upon the supply of refinery gas,

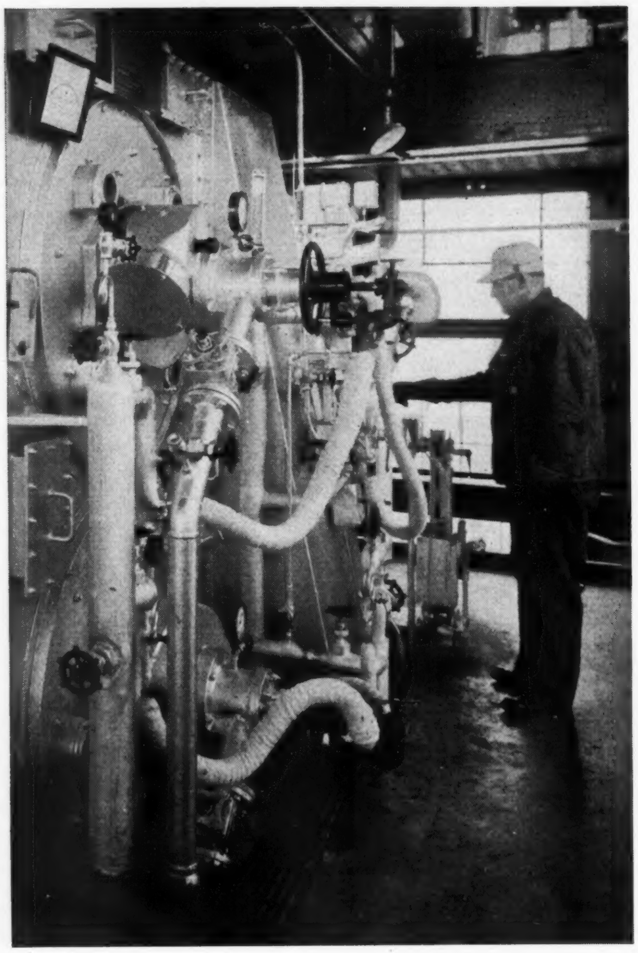

Fig. 2—Operating platform showing burners. Note the pulverized coal connection is blanked off

and the oil regulator will then supply the additional amount of oil necessary to maintain the desired steam pressure at the given output.

The refinery gas has a heating value of approximately 20,000 Btu per cu ft and has a representative composition of 36.8 per cent CH_4, 19.1 per cent C_2H_2, 23.1 per cent C_3H_8, 8.8 per cent C_4H_{10}, 0.9 per cent H_2S, 0.7 per cent C and 8.8 per cent inert gas. The oil averages around 18,000 Btu per lb. When burning gas the excess air carried is about 15 per cent, measured at the boiler outlet, and when burning oil is about 20 per cent. The calculated efficiency when burning oil is, at maximum rating, 2.2 per cent higher than with gas.

Combustion Control

Full automatic control of the fuel and air supply is obtained by means of a Bailey air-actuated control mechanism and furnace draft controller. These serve to speed up or slow down the forced- and induced-draft fans in proportion to the steam demand, and as reflected in a change in pressure on the main steam line. The forced-draft fan is equipped with both motor and turbine drive, and when the motor drive is in service, the furnace draft controller will throttle the outlet damper of the fan and maintain a fixed furnace draft. If there is a change in steam demand, it is reflected in a change in the speed of the induced-draft fan which tends to produce a change in the furnace draft. This results in the operation of the furnace-draft controller to cause an increase or decrease in the air supply to the burners.

The air pressures to the burners and the drafts in the furnace are continually registered on the control board by an Ellison draft gage which is provided with three blank scales that will be available for the second boiler. The Bailey boiler meter records the total steam produced and the volume of air flow through the boiler, the rate of air flow varying in direct proportion to a variation in steam flow. This instrument, therefore, becomes a check on the stack loss due to excess air and also on the accuracy with which the automatic controls on the fans function with a variation in steam demand.

Water Treating System

Careful analyses of the water to be used for steam generation were made over a long period in order to determine the type of treating equipment best suited to the conditions. This was especially important for the reason that no returns, except in the form of exhaust steam to the feedwater heater, are received back at the boiler plant from the refinery. The water analyses indicated that with proper coagulation and settling, followed by filtration through sand filters and then passage through a zeolite softener, the water would have a zero hardness and practically no suspended solids.

This particular water calls for the use of a continuous blowdown in order to hold the concentration within desired limits. The continuous blowdown is kept under

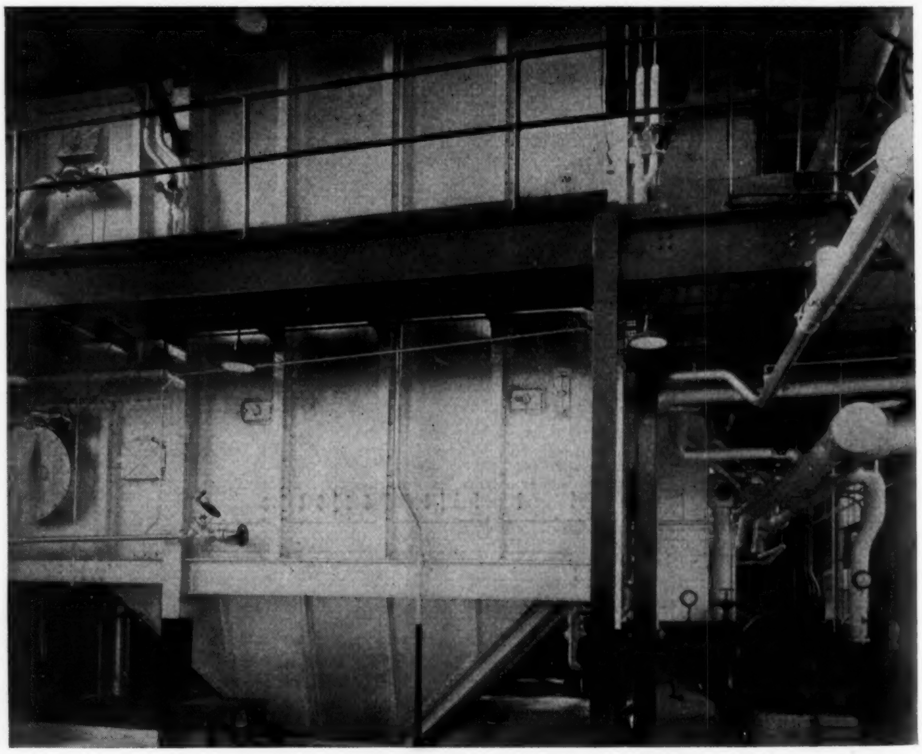

Fig. 3—Side view of boiler showing ash hopper and forced-draft fan at right

proper contol by providing a recording orifice meter which registers the amount of water removed and by providing a water-cooled sampling coil so that the operator may be able to draw samples of the blowdown water

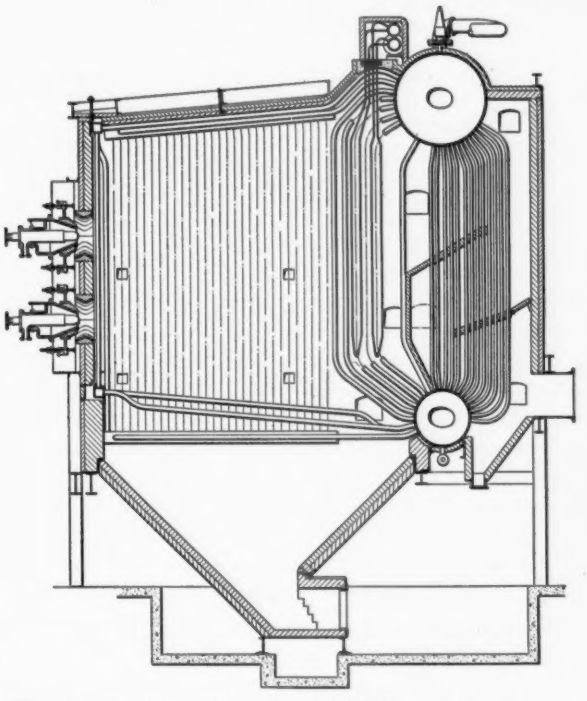

Fig. 4—Section through 65,000-lb per hr steam generating unit

for testing. This method of checking also guards against any change in the treated water such as increase in the chloride or dissolved solids.

Most of the feedwater treating equipment came from the Marcus Hook Refinery of the company, where it had been considered surplus equipment.

The water treating system is located about 800 ft from the boiler plant. It is under the control of trained men who also handle the treatment of makeup water supply required by the cooling towers which furnish treated cooling water to refinery equipment. The soft-water storage tank, however, is located adjacent to the boiler plant.

It is necessary that the operator in charge of the water treatment system know at all times the amount of water in the soft-water storage tank. In order to provide him with this information, an electrically-operated long-distance level recorder was installed, with the transmitter placed at the tank and the recorder in the water-treating control room.

The feedwater heater is elevated 25 ft above the level of the boiler feed pumps and supplies them with water

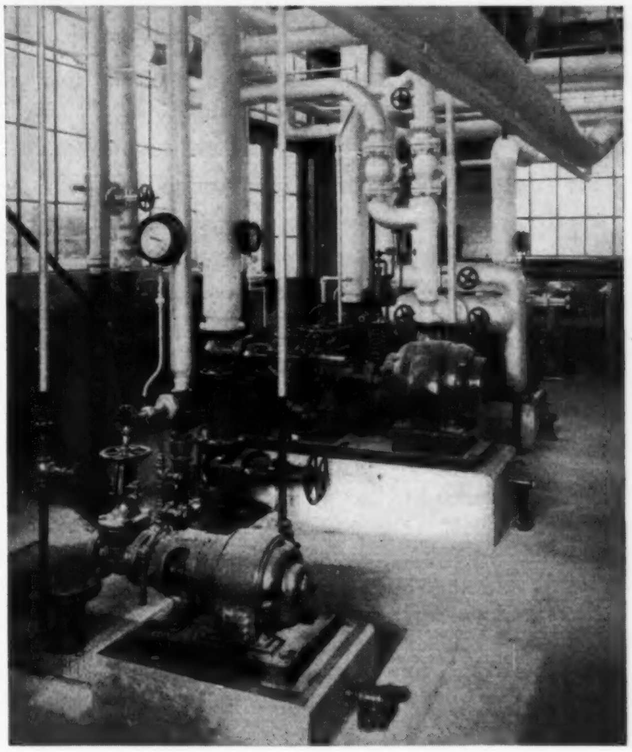

Fig. 5—Boiler feed pumps, one motor-driven and one turbine-driven; also soft-water pumps in foreground

at 218 F. These pumps, one turbine-driven and the other motor-driven, are shown in Fig. 5. The smaller pump in the foreground pumps soft water from the storage tank to the feedwater heater, not shown in the photograph.

The design and erection of the new boiler plant was carried out under the direction of Stone & Webster Engineering Corporation and it was placed in service in December 1938.

Corrosion in Partially Dry Steam Generating Tubes*

By F. G. STRAUB and E. E. NELSON
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These investigations, conducted at the University of Illinois Experiment Station, indicated that where the temperature of the metal of the tubes is below 750 F, sodium hydroxide appears to be responsible for such corrosion, whereas above 750 F corrosion may take place in the absence of sodium hydroxide and chemical treatment that is effective at lower temperatures is no longer protective.

BOILER operators have noted the presence of partially dry areas in steam generating tubes of boilers for many years. One area where this has occurred has been in the upper end of straight and bent generating tubes. The presence of the "dry areas" has been indicated by the so-called "water lines." Due to the fact that these have been in areas of relatively low heat transfer, small attention has been paid to them. In some instances attempts have been made[1] to eliminate these dry areas. In other cases the attack on the tube has been so slow that little attention has been paid to this difficulty. Recently, with the trend toward higher pressures and higher rates of heat transfer along with the more complicated boiler-water circulation, the presence of rapid corrosion in certain areas of the boiler in the absence of dissolved oxygen has again called attention to the effect of these dry areas. These areas have occurred in the upper generating tubes, in floor tubes and in sloping floor screen tubes. In several instances severe corrosion has occurred in the dry areas of the tubes while the rest of the tubes were unaffected. In other cases the dry areas are evident but no corrosion has occurred.

In order to study the cause of the corrosion in certain cases and its absence in other cases a laboratory study was made. The procedure of the laboratory work was to generate steam in a tube under such conditions that a partially dry area existed. Solutions of known composition were tested in a steam generating tube under these conditions and the effect on the tube studied.

Two procedures were followed in order to remove oxygen from the tube. The first was to evacuate the tube prior to heating and the second was to vent the air through the valve at the top as the tube was heated. No difference in results was noted and the latter method was used in all the tests to be discussed.

Results of Tests

The first test was conducted with distilled water and the tube was not inclined. No dry area existed and the tube was found to be covered with a thin film of black iron oxide and there were no indications of corrosion. Table 1 gives the results of other tests conducted. These tests were all run with the tube inclined. In all these tests the so-called "water line" was in evidence at the end of the test. In test 533 distilled water was used and no corrosion was noticeable at the end of the test. Another test was then run (534) using the same tube but substituting a sample of boiler water. This boiler-water sample was obtained from a 600-lb pressure boiler which had never experienced corrosion due to dry tubes. The A. S. M. E. ratio of this water was 3.5 and no phosphate was present. No corrosion was noticed at the end of this test. The tube was split after being run in tests 533 and 534. The water line showed clearly in

* Abstract of a paper presented at the A. S. M. E. Spring Meeting, New Orleans, La., February 23 to 25, 1939.
The results reported are part of the investigation conducted under a co-operative agreement between the Utilities Research Commission, Inc., Chicago, Ill., and the Engineering Experiment Station, University of Illinois, Urbana, Ill., and are released by permission of both parties.

[1] COMBUSTION, October 1936, p. 35.

TABLE 1—RESULTS OF CORROSION TESTS CONDUCTED ON PARTIALLY DRY STEAM GENERATING TUBES

Test no.	Duration of test, hr	Temperature: Inside	Temperature: Bottom outside	Temperature: Top outside	Solution tested: NaOH	Total alk	Na_2SO_4/alk	NaCl/alk	SiO_2	R_2O_3	PO_4	Gas generated, ml	Results of test
533	21	600	680	730	0	0	0	0	0	0	0	...	No corrosion
534[1]	22	600	690	740	180	343	3.5	0.7	14	3	0	...	No corrosion
537[2]	21	600	680	760	500	810	3.5	0.7	33	7	0	...	No corrosion
535	45	600	655	715	650	880	0	0	0	0	0	...	Corroded
532	21	600	690	750	1000	1400	0	0	0	0	0	...	Corroded
538	44	600	655	705	530	1020	0	0	0	0	200	...	Corroded
539	23	600	660	710	0	330	0	0	0	0	200	25	No corrosion
540[3]	22	600	650	725	320	600	0.8	0.5	17	24	0	196	Corroded
546	20	600	660	720	575	800	0	0	0	0	0	518	Corroded
541	20	600	690	755	575	810	0	0	35	0	0	408	Corroded
551	40	600	650	695	570	825	0.6	0	35	0	0	220	Corroded
550	47	600	640	700	570	825	2.2	0	35	0	0	50	Slight corrosion
549	20	600	650	700	570	800	4.5	0	35	0	0	10	No corrosion
542	20	600	660	710	570	1100	3.3	0.7	35	0	0	18	No corrosion
543	20	600	660	710	550	1100	3.3	0.7	0	0	0	105	Corroded
544	75	600	660	710	530	750	4.8	0.7	35	0	0	15	No corrosion
545	20	600	660	730	530	750	4.8	0.7	35	20	0	10	No corrosion
573	18	600	650	890	0	0	0	0	0	0	0	50	Corroded
575	26	600	640	830	590	815	3.0	1.0	0	0	0	375	Corroded
576	23	600	660	830	590	850	3.0	1.0	35	0	0	120	Corroded
577	22	600	640	830	530	768	3.1	1.0	35	0	60	220	Corroded

[1] Same tube used as in test 533.
[2] Same solution as in test 534 concentrated prior to test. This is a boiler-water sample.
[3] Boiler-water sample.

the top of the tube and there was no evidence of corrosion in the tube in the dry area. The boiler water was then concentrated and run in a new tube, test 537. No corrosion occurred in this tube.

A synthetic solution was then prepared containing pure sodium hydroxide in distilled water and tested in a new tube, test 535. This tube showed heavy corrosion at the end of the test. The upper dry portion of the tube had a heavy, mixed dull-black and shiny iron oxide forming on it. The lower portion showed freedom from attack.

In test 532 a synthetic solution was made containing pure sodium hydroxide. This test produced corrosion.

In test 538 a synthetic solution was made containing pure sodium hydroxide and phosphate. This test also produced corrosion and indicated that the phosphate would not prevent corrosion in the presence of sodium hydroxide. A test was then conducted (539) using trisodium phosphate alone in distilled water (200 ppm PO_4). No corrosion was detected at the end of this test and the amount of gas generated was low (25 ml).

A sample of boiler water from a boiler operating at 1250 lb per sq in. pressure which was experiencing corrosion in partially dry tubes was then tested (540). This boiler water was concentrated in a stainless-steel retort at atmospheric pressure prior to being used in this test. At the end of the test 196 ml of gas was collected and the tube showed evidence of corrosion.

In test 546 a solution of sodium hydroxide in distilled water produced 518 ml. of gas and caused heavy corrosion in the tube. The addition of 35 ppm of SiO_2 reduced the gas evolved (test 541) to 408 ml. When sodium sulphate was added to the sodium hydroxide silica solution so that the sodium sulphate was present in an amount equal to 0.6 times the total alkalinity (test 551), the gas evolved was reduced to 220 ml. When the sodium sulphate was increased still more (sodium sulphate = 2.2 $\times$ alkalinity, test 550) the gas evolved was only 50 ml and only a slight amount of corrosion could be detected. In test 549 the A. S. M. E. ratio was increased to 4.5 and the gas evolved was reduced to 10 ml with no corrosion present.

The A. S. M. E. ratio in test 542 was held at 3.3 and NaCl was added in an amount equal to 0.7 times the alkalinity. The gas evolved was only 18 ml and no corrosion could be detected. In test 543 the solution was the same as used in 542 with the silica left out. With this change 105 ml of gas was evolved and the tube was corroded.

In test 545 the solution used contained sulphates, chlorides, hydroxide, silica, and aluminates and the gas evolution was only 10 ml with no corrosion on the tube.

In order to study the effect of higher metal temperatures on the tube corrosion, tests 573–575, 576 and 577 were conducted. In test 573, distilled water was used with a maximum temperature of 890 F. This test gave 50 ml of gas and there was definite corrosion in the dry area. The other tests run at the higher temperature showed that the addition of sulphate, chloride, silica or phosphate did not prevent the corrosion.

Discussion of Results

The results which have been obtained in these tests appear to indicate that there is a relationship between the corrosion in the dry areas, the metal temperature and the composition of the water. At the same time there is a relationship between the gas generated (H_2) and the amount of corrosion. This would indicate that the chemicals in the boiler water concentrate on the dry portion of the tube. The increased wall temperature would indicate the possibility of a small area of superheat, and in this area the concentration of the chemicals might reach high values. No corrosion was detected in the portion of the tube where no dry area exists. This would indicate that a localized concentration and slight increase in temperature is essential for the corrosion to start. Since the two boiler waters tested produced such different results, it is evident that the salts in solution might have a marked effect on the corrosion in the dry area.

The corrosion in the dry area is undoubtedly produced by the action of the sodium hydroxide in the boiler water concentrating in the dry areas. As long as the sodium hydroxide is in a dilute solution in the boiler water the water merely forms a thin impervious film of iron oxide which in turn protects the steel from further reaction with the water. When the sodium hydroxide concentrates in the dry areas the iron-oxide film is dissolved or penetrated by the concentrated sodium hydroxide, thus exposing the steel tube to further action with the water and the subsequent evolution of hydrogen. The oxygen from the decomposition of the water combines with the iron to cause the corrosion. If the metal temperature is not too high, the presence of silica tends to retard the action of the caustic solution. When sodium sulphate is present in relatively large amounts, it apparently precipitates as an insoluble salt and protects the steel.

If the metal temperature is kept below 750 F the attack appears to be definitely related to the dry areas and the chemical composition of the boiler water. However, if the metal temperature is above 750 F, the attack occurs in the absence of sodium hydroxide and is not prevented by chemical treatment. This appears to explain the different conditions which have been found in different boilers. Thus if the dry areas occur where the metal temperature is below 750 F, the chemicals present in the boiler water would have a marked effect on the corrosion taking place. If the metal temperature in the dry areas should exceed 750 F, the corrosion will proceed in such a manner that chemical treatment will have practically no effect in preventing it.

The fact that the metal temperature in a dry area has to be controlled within such narrow limits would indicate that the prevention of corrosion in these areas is a mechanical problem and not chemical.

Summary of Conclusion

The results of these tests may be summarized as follows:

1. Such corrosion occurs only in partially dry areas.
2. If the metal temperature is below 750 F, sodium hydroxide appears to be the active constituent in the boiler water causing the corrosion.
3. If the metal temperature is below 750 F, the corrosion may be controlled by modifying the boiler water as follows: (*a*) reducing the free causticity to zero, and (*b*) adding other salts such as sulphate, silicate, etc.
4. If the metal temperature is above 750 F, corrosion takes place in the absence of sodium hydroxide and chemical treatments effective at the lower temperature are no longer protective.

Developments in Central Station Power Plants

By A. D. BAILEY

Chief Operating Engineer,
Commonwealth Edison Company

In the following excerpts from a paper before the Midwest Power Conference at Chicago, April 5–7, the author discusses some of the problems incident to further improvements in the steam cycle, particularly the trend toward higher steam pressures and temperatures. He briefly reviews fifty-one steam generating units in the 1200–1400-lb class, installed or on order, and the turbine-generators which they serve. The conclusion is reached that present trends will continue as long as the savings due to improved efficiency are not overbalanced by increased fixed charges.

IN the early development of the steam cycle, the saving due to some improvement was large in percentage and the base on which that percentage was figured was relatively large; but now that the physical limitations of the steam cycle are being approached, both are continually decreasing and the law of diminishing returns is asserting itself. The size of modern equipment and its output are so large, however, that savings of small unit magnitude become unbelievably large in the aggregate. The problems involved in the balancing of increased operating savings against increased fixed charges due to increased capital costs, however, are better understood than ever before, and the engineer has a better picture of the economic balance which governs the ultimate cost.

While it took many generations to reach steam pressures of 200 lb, the step to 600 lb was accomplished in about twenty years, and that to 1200 lb occurred almost simultaneously, although its general acceptance is comparatively recent. According to some, we are already on our way to pressures in the 2000-lb range and above. Orders have been placed for two installations of boilers and turbines, one to operate at 2000 lb and the other at 2400 lb. The first is being erected and should be in operation soon.

Progress toward higher steam temperature has been fairly uniform but the engineer has been limited by the materials available. Cast iron was permissible for temperatures in the 500 F range, steel for possibly 750 F, and progress beyond that temperature has been determined by alloys which the metallurgists have been able to develop. At present the materials economically available hold steam temperature to 950 F for general use, although the Detroit Edison Company's experimental installation operated successfully at 1000 F for a considerable period. There is serious question whether we are approaching the limit of stability of the power medium itself, which introduces new problems entirely independent of those incident to the effect of pressure and temperature alone on materials of construction.

Research on Steels for High Temperature

Increased steam pressure is not giving as much concern as increased steam temperature, and the effect of temperature on metals is receiving more attention today than ever before. Not only are the research laboratories of the producers of steels and alloys and the equipment manufacturers busy on this subject, but one of the oldest standing committees representing the A. S. M. E. and the A.S.T.M. is diligently employed both in seeking new information and in coordinating information from all sources. "Creep," which may be roughly defined as the growth of metal at high temperature under stress, is now the measure of the usefulness of a given material. In steam generating equipment, creep is limited to 1 per cent in 100,000 hr, (12 yr) while in some parts of turbines it is limited to 1 per cent in 1,000,000 hr.

Materials of construction, even the best, seem to be more susceptible to attack under high temperature and practically all types of failure are accelerated. Rapid changes in temperature are a matter of great concern, as the uneven heating of large bodies of material necessary for high operating pressure causes them to distort or even pull themselves apart. Uniform cross-section must be maintained as closely as possible throughout a given piece of material. The old methods of bolting and riveting are disappearing, and it is a serious question whether the rolled joint is not destined to be the next victim. Welding has become almost universal; boiler drums are now being welded up to 4 $^7/_8$ in. thick, and on the 2000-lb boilers the drum shells, which are forged from a solid billet, approach 8 in. in thickness, the ends being turned down and the heads welded on. The welding of pipe joints is standard practice. We also find welding becoming the standard method of fastening on ash pits, ducts, casings, breechings, stacks, tanks and parts of the supporting steel work.

Even the materials used for heat insulation have undergone a change as those that were successful at lower temperatures break down under more severe conditions; and with increased temperature the material which con-

trols radiation losses as well as the comfort, to say nothing of the physical danger to the operators, becomes exceedingly important.

The modern high-pressure steam generator bears little resemblance to its predecessor of a generation ago. In the first place, the decreasing difference in density between water and steam has affected boiler design from a circulation standpoint. Forced circulation is becoming increasingly popular in Europe and is being given serious consideration in this country. Increasing rates of heat transfer have made clean surfaces absolutely essential, and the development of the water-cooled furnace has changed the design of the whole unit. It has become the most important heat-absorbing section of the steam generator, and that part of the installation which we have been accustomed to call the boiler has been reduced to a point where it serves merely as a screen for the superheater. In some newer designs, it has disappeared altogether. Increases in steam temperature have made it necessary to increase the size of the superheater, and to put it in the path of the furnace gases at as high a point in the temperature scale as possible, consistent with good operation. The economizer is not changing so much in size as in its location in the temperature scale. While it is furnishing water at higher temperature to the boiler proper, the temperature of the feedwater with which it is supplied has been continually increased in order to get the greatest possible benefit of steam extraction in the prime mover. In order to obtain the proper reduction in flue gas temperature necessary for economical operation, the air preheater has been increased in size with a resultant increase in the temperature of the air supplied to the furnace for combustion purposes, which has been most beneficial.

Distribution of Heat-Absorbing Surfaces

In a modern installation, over one-half of the total heating surface of the entire steam generating unit is in the air preheater, although it may absorb only about 10 per cent of the heat reclaimed. The economizer has approximately 15 per cent of the surface, and absorbs about 10 per cent of the heat. The superheater, which may have anywhere from 12 to 20 per cent, or even more, of the surface, depending on its location, absorbs 20 per cent or more of the heat, while that part which we formerly called the boiler may have only 5 or 6 per cent of the surface, and absorbs a like percentage of the heat. The furnace water walls, which may have 5 or 6 per cent of the surface, may absorb nearly half of the heat utilized by the entire installation.

Under the exacting conditions of the present steam cycle, the water used for steam is developing traits and peculiarities heretofore unexpected. A generation ago it was thought that a little scale on the inside of a boiler was a good thing. Water treatment was a common term meaning almost anything and a moderate amount of condenser leakage was considered advisable, as in this manner makeup was obtained which was fairly well strained. But now all this has been changed; scale is absolutely prohibited; the slightest trace of oxygen in the water causes pitting; the loss or the stoppage of water supply for any part of the water-heating surface results in immediate rupture; the amount of makeup is reduced to a minimum; and condenser leakage is spoken of in minor fractions of a per cent. What little makeup is used must be evaporated and then treated, if treatment is necessary. The concentration of water in a steam generator is carefully watched to avoid the carry-over of solids into the superheater and turbine, and the devices developed for scrubbing the steam before it leaves the boiler drum are most ingenious.

The control of steam temperature must be exact so that fairly constant temperature will be obtained over a wide range of loading. Particular care must be taken against overheating as this might be fatal to the material in the high temperature part of the superheater, and to the turbine. As a consequence we find steam generators with selective gas paths so that the superheater can be by-passed under certain load conditions. This design has generally taken the place of desuperheaters which were previously installed. We also find in some of the taller furnaces that booster burners have been installed near the top of the furnace for raising the steam temperature during low load periods.

Fuels Influence Heating Surfaces

More than ever before the heating surface for making steam is being designed to suit the peculiarities of the fuel to be used. With pulverized coal installations, the temperature and the velocity of the furnace gases entering the first tube bank are most important, particularly if the coal has a high percentage of ash which fuses at relatively low temperature. At such locations, wide tube spacing is becoming standard practice. It is desirable to keep the furnace exit gas temperature as low as possible in order to reduce slagging and at the same time to keep it as high as possible in order to get a maximum amount of heat out of a minimum amount of heating surface. Further than that, the entire setting must be so designed that all of the heating surfaces may be cleaned while the unit is in operation, otherwise the ultimate in operating efficiency will not be obtained nor will there be the high percentage of operating availability which modern conditions demand.

As the availability of steam generating equipment has been made to equal that of the steam turbine, the size of steam generating units has been increased until the single-boiler, single-turbine installation has become quite general.

During the depression and up to three years ago, very little of this equipment was ordered or built; and although since that time orders have been placed for steam generators and turbines operating at pressures all the way from 250 lb to 2400 lb, there has been a decided tendency toward the 1200-lb cycle which has been influenced by the fact that with a steam temperature of 900 F or more, reheating can be avoided.

Recent High-Pressure Units

In the 1200-lb class, ninety-two steam generating units have been ordered or built, of which fifty-one are grouped in the last three years—each installation consisting of from one to three steam generators per turbine unit; ten turbines have one steam generator each, thirteen have two and five have three. Only two operate at temperatures below 900 F; four have feedwater temperatures below 325 F, and in one case the feedwater temperature will be 475 F. The size of the individual steam generator ranges from 60,000 to one million pounds of steam per hour. Eleven have a capacity of 200,000 lb per hr,

six of 375,000 lb and seven of 500,000 lb. Fourteen are of the straight-tube design, twenty of the bent-tube design and seventeen are of the radiant type. One is stoker fired; thirty-three burn pulverized coal; seven burn pulverized coal or fuel oil; one burns pulverized coal, fuel oil or natural gas; and nine burn natural gas, fuel oil or refinery acid sludge. Twenty-three furnaces have a heat liberation rate of from 21,000 to 30,000 Btu per cu ft, twenty-five have a rate of from 31,000 to 40,000 Btu, and three have a rate of 56,000 Btu. Of the thirty-three pulverized coal furnaces, seventeen have dry bottoms.

Considering now the 1200-lb steam turbine field, the first unit in this class was a 3000-kw, superposed unit ordered in 1923, and the largest is the 150,000-kw, triple-tandem condensing unit at State Line Station. Up to the end of 1938, fifty-six turbines in this class had been ordered or built, with a total capacity of 2,300,000 kw. Twenty-nine of these fifty-six turbines were ordered in the last three years (fourteen in 1936, ten in 1937 and five in 1938) and range in size from 5000 to 110,000 kw, including three 25,000-kw units, seven 35,000-kw units and five 50,000-kw units. It is encouraging to note that three large superposed units and a large condensing unit in this class have already been ordered this year. All but two of these twenty-nine turbines use steam at 900 F or above, and four of them will operate at 1400 lb peressure. Only one uses reheat. Twenty-six turbines, having a capacity of 60,000 kw or less, operate at 3600 rpm, and two larger than 60,000 kw operate at 1800 rpm. One of the most notable units is an 80,000-kw, 1800-rpm turbine which will be built with a single casing. Eighteen units exhaust steam to older turbines at 200 to 300 lb; one extracts steam to old turbines at 250 lb; one exhausts steam to process at 385 lb; three extract steam to process at 240 lb, and only six expand steam completely and exhaust to the condenser.

Extent of Hydrogen Cooling

There is a decided tendency toward the use of hydrogen for generator cooling, particularly in large units, and especially in the 3600-rpm class. In the list previously given, six in sizes below 20,000 kw are air-cooled; in the group from 25,000 to 50,000 kw, six generators are air-cooled, and thirteen are hydrogen-cooled; and above 50,000 kw, all four units are hydrogen-cooled.

The rejuvenation of old generating equipment by the superposition of high-pressure turbines has generally resulted in the complete overhauling of condenser equipment in order to reduce leakage. Invariably this consists of checking all the tubes, improving methods of sealing them in the tube sheets, and in improving the steam path through the condenser by the removal of cooling surface. Of the new condensers on order, the majority are of the two-pass type, but this may be explained by the statement that many of the installations are on inland streams where condensing water is not plentiful. Welded-shell construction is now almost universal, and some condensers are now being installed with a welded connection to the turbine exhaust. The efficiency of condenser tube surface has been increased by modern designs, but the manufacturers are continuing their researches in an effort to make further improvements.

In the steam-turbine field, the most notable development is probably the standardization of turbine-generators, which has been developed recently by the Subcommittee on Standardization of the National Defense Power Committee. These preferred standards set up a list of ratings, speeds, steam pressures and temperatures, the number of extraction openings and the pressures and temperatures at these locations, the relation of turbine capacity to generator capacity, the power factor of the generator and the type of cooling system to be applied to the generator, whether air or hydrogen. They apply to both condensing and superposed turbines.

There is considerable difference of opinion as to how this standardization of turbines will work out. It should be beneficial, but it must not be allowed to retard in any way the development of better and more economical equipment. However, as both the manufacturers and the users are represented on the Committee, there is every reason to believe that the code can be changed to take care of advances in the art of turbine manufacture and power production.

In conclusion, it should be noted with satisfaction that the trend toward higher steam pressure and temperature, with the resulting improved efficiency, has not resulted in increased unit cost for the equipment. This trend toward higher steam pressure and temperature and improved equipment will continue as long as the saving due to improved efficiency is not overbalanced by the increase in fixed charges resulting from additional capital cost.

Heat Transmission in Combustion Chambers

With reference to the review of Steam Engineering Abroad in your December 1938 issue we would respectfully draw your attention to the article reviewed under "Heat Transmission in Combustion Chambers." In this the expression used for calculating heat transfer by radiation is given as follows:

$$R = 0.172 \times A \left\{ \frac{(T_F)^4}{(100)} - \frac{(T_{TW})^4}{(100)} \right\} \alpha \times \delta$$

in which α is the correction factor to allow for the absorptivity of the heating surface and the emissivity of the fuel undergoing combustion, while δ is the correction factor for the disposition of the heating surface in relation to the manner in which it "sees" the furnace; this expression being correct when used with the above modifications.

In your synopsis however, you mention that, for different methods of firing, the same basic formula is employed, the only modifications being in the factor δ. We would point out that we have established standard modification factors for the disposition of the heating surface and these are well known for our standard pitching of boiler tubes and water walls whether close or open pitch, so actually the only factor we modify is the factor α (correction factor for absorptivity of heating surface and the emissivity of the fuel) and not the factor δ as mentioned in the resumé.

W. C. Carter,
John Thompson Water Tube Boilers, Ltd.,
Wolverhampton, England

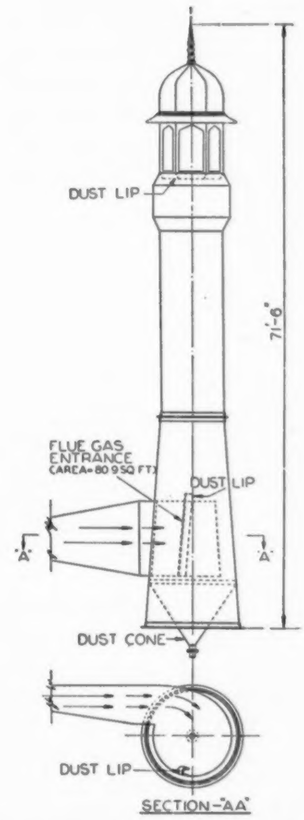
STEAM ENGINEERING ABROAD

As reported in the foreign technical press

Novel Design of Chimney

Engineering and Boiler House Review (London) of March describes an unusual design of chimney employed at the Hussain Sagar Power House at Hyderabad, India, which combines native architectural features with means for mitigating the dust and cinder nuisance, resulting from the burning of very fine coal (0 to $^3/_8$ in.) on stokers.

Each chimney serves two boilers and extends 46 ft above the roof. Below the roof level the chimneys splay outward, as shown in the accompanying sketch. The gases after leaving the economizer and induced-draft fan enter the base of the chimney at a tangent, thus creating a vortex which persists throughout the upward passage of the gases until they finally emerge through the arches beneath the dome. On the side of the chimney opposite the gas entrance is fixed a steep helical lip which opposes the direction of the gas vortex and deflects the heavier particles downward into the conical base. Further separation of the dust particles takes place by centrifugal action throughout the upward passage of the gases and causes a continuous rain of dust down the inside walls.



Elevation of chimney and section through base indicating tangential entrance of gases

There remain two final stages of the process. The first occurs when the minaret expands, about 22 ft above the roof. This causes a reduction in the velocity of the gases and further separation of dust. The second is effected by an inverted conical dust lip which acts as a baffle where the gases again converge before their final exit.

The dust and cinders are withdrawn from the base of the chimney through a 6-in. pipe and are carried away by an hydraulic sluicing system.

It is claimed that, except during very heavy loads or momentary load fluctuations, the stack discharge is comparatively dust free.

The power house is situated close to a residential district and this form of chimney has met the requirements without resorting to a heavy expenditure for dust recovery equipment.

Operation at Hams Hall Station

A paper by F. W. Lawton before the Institution of Electrical Engineers on "The Design and Operation of Hams Hall Power Station" is reported in *Engineering* (London) of March 17. This station, which supplies the City of Birmingham, was originally placed in service in 1929 with a capacity of 60,000 kw. This has lately been extended to 240,000 kw. The first eight boilers were fired with pulverized coal but, because of a change in the fuel situation, the next six units were stoker-fired, as were also those of the third section of the boiler house. The latest extension, namely, Hams Hall "B" Station, which is now under construction will revert to pulverized coal firing due to the large capacity boilers and the burning of low-grade Midland coals. It is estimated that this will result in an annual saving equivalent to nearly $200,000, notwithstanding the additional cost of the electrostatic dust-recovery system.

The paper contains operating data on Station "A" for the years 1935, 1936 and 1937, during which the respective overall station efficiencies (based on kilowatt-hours sent out) were 21.78, 21.71 and 21.42 per cent, with corresponding load factors of 53.2, 44.6 and 51.6 per cent. The total operating costs (including fuel, labor, maintenance and supplies) for these years were, 0.1065, 0.1273 and 0.1482 pence per kilowatt-hour sent out. This corresponds to approximately from 2 to 3 mils. The increase is due largely to a 50 per cent advance in the price of coal.

Test data are given for two of the boilers, one pulverized-coal-fired and the other stoker-fired, each equipped with an economizer and an air heater. Under steam conditions of 361 lb pressure and 722 F steam temperature and an average load of 171,000 lb per hr, the pulverized-coal-fired unit showed a net efficiency of 83.22 per cent; whereas the stoker-fired unit under a load of 250,383 lb per hr, 358 lb pressure and 752 F

steam temperature, showed a net efficiency of 83.28 per cent. The respective heating values of the coal were 10,904 and 10,451 Btu per lb.

With reference to operating experience Mr. Lawton observed that the straight-tube boilers, fired with pulverized coal of about 7 per cent ash content, require cleaning after 600 hr steaming and with 18 per cent ash coal this period is reduced to 350 hr. This is due to bird-nesting taking place in the first few rows of tubes. On the other hand, the bent-tube boilers, fired with pulverized coal, do not become choked so rapidly and usually 1500 hr of steaming between cleaning is practicable with high-ash, low-grade coals. The stoker-fired boilers require cleaner coals with a coking index not less than $4^1/_2$. Choking of the superheater first takes place and cleaning after 750 hr is usually necessary. The pulverized-coal-fired boilers can be brought up to pressure from a cold condition in $1^1/_2$ hr, 5 to 6 tons of fuel being required, whereas the stoker-fired units require from 2 to $2^1/_2$ hr and about 10 tons of coal.

Pressure Drop in Pipe Lines

Zeitschrift des Vereines deutscher Ingenieure of December 18, 1938, contains a digest of an article by E. Zimmerman analyzing pressure drops in steel pipe lines.

In straight circular pipes, the pressure drop of a flowing fluid is represented by the expression,

$$\Delta P_r = \lambda \frac{l w_m^2}{2 g d v_m} = \lambda \frac{6375 l G^2 v_m}{10^3 . d^5} \text{ (kg per sq m)}$$

and in pipe bends by

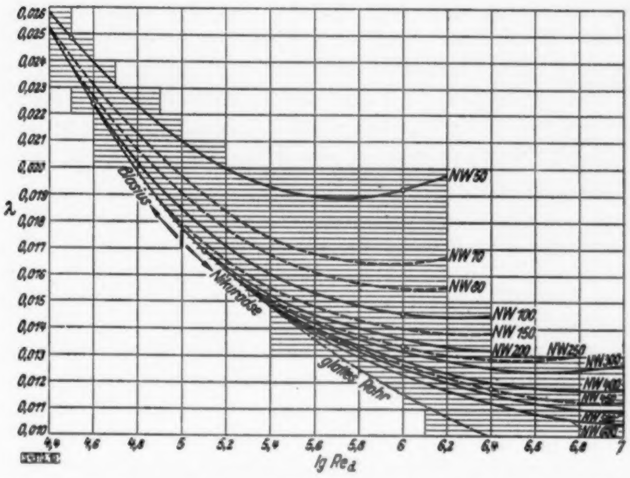
$$\Delta P_g = \zeta_g \frac{w_m^2}{2g v_m} = \zeta \frac{6375 G^2 v_m}{10^3 . d^5} \text{ (kg per sq m)}$$

where l = length of pipe, in meters
d = inside diameter of pipe, in meters
G = fluid flowing per hour (tons per hr)
v_m = specific volume of the fluid (cu m per kg)
w_m = mean velocity of fluid (m per sec)
λ and ζ_g = friction factors.

Values of λ heretofore established for straight pipes have differed materially so that for reasons of safety the highest values have been used. To obtain reliable values which require no safety factors, very accurate measurements of pressure losses were made on pipes of 50, 100, 250 and 450 mm diameter. Tests were carried out on a number of different pipes of the same diameter and a curve selected as characteristic, and, together with the remaining test curves of measurements for different sized pipes, the accompanying chart was drawn giving values for λ between the pipe sizes 50 and 600 mm for Reynolds numbers[1] up to 10^7.

When compared with the usual values employed heretofore those of the chart are in part materially lower and may be used without additional factors for new steel pipe, such as used for handling steam or for long distance gas lines. They were determined from measure-

[1] The friction factor is a function of pipe size, d, in meters; the velocity w is in meters per sec; density s, is in kilograms per cubic meter; and absolute velocity u, in poises, varies as some function of $\frac{wds}{u}$, known as the Reynolds number, Re. For the solution of any problem in turbulent flow through new steel pipes, first calculate $Re = \frac{wds}{u}$, determine log Re and find the corresponding value of λ from the chart.



Friction factors of commercial straight steel pipes of from 50 to 600 mm nominal size

λ = friction factors; $\lg Re_d$ = Reynolds number
glattes Rohr = smooth pipe
Blasius, Nikuradse = experimenters
NW = nominal size in mm.

ments taken under operating conditions. For high velocities of expansive fluids the following percentage increases in λ are to be added:

Velocity	50 m per sec	100 m per sec	150 m per sec
Superheated steam, per cent	1	5	10
City gas (at 20 C), per cent	2	8	15
Air (at 20 C), per cent	3	15	30

Similar measurements were carried out for resistances on 90-deg bends and on formed pieces made up of several such bends. Essentially the resistance becomes less as the length of the half measure of the bend R increases. The resistance of the bend drops materially up to $R = 2d$, after which its drop is not so rapid. Measurements were carried up to $R = gd$. It was found that, contrary to the usual accepted assumption, when several 90-deg bends were formed into *S*- or *U*-bends, that the resistance of the individual bend dropped more or less, but in no case did it rise, even where straight sections occurred between bends. The added factors to the resistances of the individual bends heretofore used are superfluous.

These measurements of unit resistances cannot, of course, cover the entire field, but only represent an attempt to approach the problem from the practical side.

Steam Transmission at Billingham

In a paper before the Institution of Mechanical Engineers on "Transmission of Superheated Steam over Long Distances," reported in *Industrial Power and Fuel Economist* (London) for February, Professor Geneve cites the Billingham Works of Imperial Chemical Industries. Briefly, this plant contains eight 215,000-lb per hr, pulverized-coal-fired boilers supplying steam at 675 lb and 856 F to three 12,500-kw back-pressure turbine-generators exhausting at 290 lb and 650 F to a low-pressure receiver. From this receiver part of the steam supplies two 12,500-kw condensing turbine-generators and part is transmitted to process. Extraction steam from the low-pressure turbines is supplied to quadruple-effect evaporators for boiler makeup. The total output of the boilers is over 26 million pounds of steam per day, of which 57 per cent is used for process.

The maximum distance of steam transmission is ap-

proximately a mile for both the 290-lb steam and the 30-lb low-pressure supply, the former being utilized in driving non-condensing engines and turbines located in remote parts of the works, and the exhaust from which is used in evaporating vats. Several mixed-pressure turbines serve to maintain a balance between power and heating steam requirements.

Testing Pipe Joints

In a recent paper before the Institute of Marine Engineers (Great Britain), F. J. Cowlin and J. P. Chittenden described a variety of methods for connecting lengths of steam pipe and also an ingenious method for comparing the performances of the different joints. Hydraulic pressure is built up in the joint which, for test purposes, is maintained tight by a static load of definite amount. Sooner or later leakage is seen to occur, and then a note is made of the pressure producing it. The internal pressure load tending to open any joint, in which the jointing material effects a seal over the entire flange face, would be equal to the product of the pressure intensity and the cross-sectional area of the pipe. If, however, the flange springs a little, the seal may not be perfect except near the bolt circle, in which event the opening force would be much more.

The ratio of the pressure actually needed to open a joint to the pressure theoretically required is taken as the joint efficiency. Tests quoted in the paper showed that efficiencies of ordinary flanged joints may in practice fall to 50 per cent, or even less—*The Power and Works Engineer*, March 1939.

EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

as reported by equipment manufacturers to the Department of Commerce, Bureau of the Census

Boiler Sales

	1938 Water Tube No.	1938 Water Tube Sq Ft	1937 Water Tube No.	1937 Water Tube Sq Ft	1938 Fire Tube No.	1938 Fire Tube Sq Ft	1937 Fire Tube No.	1937 Fire Tube Sq Ft
Jan.	52	201,151	52	256,368	35	42,752	65	84,889
Feb.	48	185,257	51	198,957	45	55,173	74	89,133
Mar.	58**	238,830**	142	791,168	50	49,039	150	211,733
Apr.	48	195,910	60	322,669	37	52,421	75	69,937
May	60	330,653	113	589,347	61	68,288	83	130,782
June	58	190,242	76	330,524	63	86,975	77	100,585
July	67	271,561	83	350,917	69	98,074	83	101,058
Aug.	56	190,762	68	273,726	53	69,494	109	138,501
Sept.	45	169,241	57	241,186	58	62,794	77	103,024
Oct.	51	191,932	66	259,273	46	48,231	59	60,390
Nov.	55	198,589	41	247,882	38	39,198	46	50,644
Dec.	67	335,297	52	196,464	42	59,821	43	38,129
Jan to Dec. Inclusive	665	2,699,425	861	4,058,481	597	732,260	941	1,178,805
	1939				1939			
Jan.	73**	372,911**			49	61,911		
Feb.	70	309,235			45	58,028		
Jan.-Feb.	143	682,146			94	119,939		

** Revised

Mechanical Stoker* Sales

	1938 Water Tube No.	1938 Water Tube Hp	1937 Water Tube No.	1937 Water Tube Hp	1938 Fire Tube No.	1938 Fire Tube Hp	1937 Fire Tube No.	1937 Fire Tube Hp
Jan.	28	9,484	63	25,278	76	10,991	140	21,636
Feb.	36**	12,450**	45	16,591	76**	12,216**	120	20,650
Mar.	54	18,820	80	38,074	52	9,434	179	24,709
Apr.	35	12,698	72	37,185	71	11,058	154	23,064
May	32	10,830	65	26,327	106	15,342	137	21,443
June	28	9,284	49	19,787	166	21,378	186	26,627
July	45	17,449	63**	23,135**	191	24,816	251	34,253
Aug.	35	10,991	58	21,998	269	33,199	394	53,096
Sept.	47	16,250	40	11,359	279	28,780	384	46,893
Oct.	42	15,809	53	17,727	300	44,111	310	39,837
Nov.	27	8,151	31	12,171	201	26,382	190	21,525
Dec.	47	17,617	24	7,130	172	22,500	183	27,613
Jan. to Dec. Inclusive	456	159,833	659**	262,834**	1,959	260,207	2,628	361,346
	1939				1939			
Jan.	44	17,067			145	17,842		
Feb.	46	20,715			140	18,217		
Jan.-Feb.	90	37,782			285	36,059		

* Capacity over 300 lb of coal per hour
** Revised.

Pulverizer Sales

	1938 Water Tube No. N.†	E.†	Cap. Lb Coal/Hr	1937 Water Tube No. N.†	E.†	Cap. Lb Coal/Hr	1938 Fire Tube No. N.†	E.†	Cap. Lb Coal/Hr	1937 Fire Tube No. N.†	E.†	Cap. Lb Coal/Hr
Jan.	5	—	40,500	35	7	554,900	1	—	1,000	—	2	1,700
Feb.	7	1	38,020	2	6	68,300	—	1	800	—	4	3,600
Mar.	—	2	26,100	59	3	713,440**	—	1	700	1	1	2,000
Apr.	2	2	26,600	24	1	257,100	—	—	—	—	2	1,100
May	5	2	33,690	22	—	276,800	—	—	—	—	—	—
June	7	2	49,440	15	—	99,150	—	—	—	—	—	—
July	3	1	23,000	5	6	44,250	—	—	—	—	—	—
Aug.	8	5	155,390	10	15	215,600	1	—	1,000	—	—	—
Sept.	2	1	58,500	14	3	75,900	—	—	—	2	—	2,500
Oct.	2	—	7,650	10	16	302,450	—	—	—	—	—	—
Nov.	7	2	139,800	7	8	220,000	—	—	—	—	1	1,000
Dec.	15	1	208,700	11	—	104,700	—	—	—	—	—	—
Jan. to Dec. Inclusive	63	19	807,390	214	65	2,924,590**	2	2	3,500	3	10	11,900
	1939						1939					
Jan.	10	—	79,000				—	—	—			
Feb.	7	—	89,600				—	—	—			
Jan.-Feb.	17	—	168,600				—	—	—			

† N—New boilers E—Existing boilers.
** Revised.

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